IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Neal J. Miller
William Jerry Parkinson
Ronald E. Smith

Serial No.: 10/051,324 EXAMINER: Cooley, Charles

Filing Date: 01/22/2002 Art Unit: 1723

For: SYSTEM AND PROCESS FOR SEPARATING MULTI PHASE MIXTURES USING THREE PHASE CENTRIFUGE AND FUZZY LOGIC

Attorney Docket No. Miller 01-01

AFFIDAVIT UNDER 37 CFR §1.131

Mail Stop RCE
Commissioner For Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Neal J. Miller, William Jerry Parkinson and Ronald E. Smith under penalty of perjury declare as follows.

1. We are the co-inventors in the above application.

2. Co-inventor William Jerry Parkinson is the author of the document dated July 2001, entitled "Fuzzy and Probalistic Control Techniques Applied to Problems of the Chemical Process Industries", which was cited in the Office Action dated 04/13/2004 in support of the rejections of claims 1, 3-6, 8, 10-17, 19, 22-25 and 27-32 of the present application under 35 USC §102(a). This document,

hereinafter referred to as the "Thesis", was submitted by co-inventor William Jerry Parkinson to the Department of Electrical Engineering, University of New Mexico, Albuquerque, New Mexico, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

3. The system and process claimed in the present application were reduced to practice in the United States prior to July 2001, the date of the "Thesis", as evidenced by the following showing of facts.

3A. From about June of 1993 to October of 1996 the co-inventors designed, built and tested a "system for separating a multi phase mixture", comprising a three phase centrifuge and an original control system for the centrifuge. This work was performed at the Los Alamos National Laboratory in Los Alamos, New Mexico, at Centech Inc. in Casper, Wyoming, and at field locations in the United States.

Attached to this Affidavit is Exhibit A comprising pages 24-29 of the "Thesis", which makes reference to the design, building and testing of the three phase centrifuge with the original control system.

Attached to this Affidavit is Exhibit B, United States patent application serial no. 09/357,339, filed 07/14/1999 entitled "Automatically Controlled Three Phase Centrifuge And Method For Separating Multi Phase Mixtures", which is the parent application of the present application. The parent application demonstrates reduction to practice of the "system for separating a multi phase mixture" with the original control system. In this regard, the centrifuge is described on page 19, line 21 to page 30, line 24 of the

specification of Exhibit B. The control system is described on page 5, line 13 to page 6, line 14 of the specification of Exhibit B. The fuzzy logic rules are described on page 10, line 20, to page 12, line 16 of the specification of Exhibit B.

3B. From about August of 1999 to December of 2000 the co-inventors designed, built and tested an advanced version of the "system for separating a multi phase mixture" having an advanced control system with feed forward and feedback fuzzy logic rules as described and claimed in the present application. This work was performed at the Los Alamos National Laboratory in Los Alamos, New Mexico, at Centech Inc. in Casper, Wyoming, and at field locations in the United States.

Attached to this Affidavit are Exhibits C-I which demonstrate a reduction to practice of the advanced version of the "system for separating a multi phase mixture" having the advanced control system.

Exhibit C comprises pages 15-24 of the lab notebook of co-inventor William Jerry Parkinson, dated between 07/27/1999 and 08/17/1999. Exhibit C describes rules for the advanced control system.

Exhibits D-I are quarterly reports prepared by co-inventor William Jerry Parkinson for John Ford at the National Petroleum Technology Office of the Department of Energy. Exhibits D-I are Department of Energy internal documents, which to the knowledge of the inventors have not been published or made available to the public. Exhibits D-I chronicle the design, building and testing of the "system for separating a multi phase mixture" having the advanced control system, beginning with Exhibit D (fourth

quarter FY99) and ending with Exhibit I (first quarter FY01).

4. The undersigned further declare that all statements made herein of their own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful, false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful, false statements may jeopardize the validity of the application or any patent issuing thereon.

Neal J. Miller 8-30-04

NEAL J. MILLER Date

William Jerry Parkinson 9/8/04

WILLIAM JERRY PARKINSON — Date

Ronald E. Smith 9-8-04

RONALD E. SMITH — Date

LA-13845-T
Thesis

EXHIBIT A

Fuzzy and Probabilistic Control Techniques Applied to Problems of the Chemical Process Industries

EXHIBIT A

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

LA-13845-T
Thesis

Issued: July 2001

Fuzzy and Probabilistic Control Techniques Applied to Problems of the Chemical Process Industries

William Jerry Parkinson

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

conflict resolution code that all work in consort with the fuzzy feedback controller. These systems all demonstrate the utility of fuzzy controls applied to CPI problems.

The set of control systems used on the centrifuge also provide a very diverse and difficult set of problems with which to test the probabilistic controller. These problems are complete and "real world."

2.2 BACKGROUND AND ASSESSMENT OF THE CENTRIFUGE TECHNOLOGY

Centech, Inc. has developed a novel, three-phase centrifuge process for the recovery of oil from tank bottoms and sludge. The process was a winner of a 1993 R&D 100 award, and it is protected by a 1992 patent [23]. Centech has been in business for over a decade and has used this technology to successfully treat nearly 1,000,000 barrels of tank bottoms and sludge including completion/workover, production, industrial, and refinery wastes. The process equipment is a one-of-a-kind, three-phase decanter centrifuge that only Centech personnel can successfully operate. Documented results show that this three-phase centrifuge is capable of separating tank bottoms and sludge into three product streams: pipeline quality oil, water with 2-3ppm total dissolved hydrocarbon, and land-fillable solids [24]. Unlike similar techniques, the Centech process can often achieve these separation levels without the addition of any separation-enhancing chemicals. The economic analysis of a field test near Hobbs, New Mexico demonstrated that the revenue received from the sale of the recovered oil negated the cost of the service, resulting in a break-even venture. The reduction in liability associated with the reduction in waste volume was not included in the economic analysis. These savings normally amount to much more than the profit from selling the cleaned oil. However,

with dwindling oil reserves and rising oil prices, the money obtained from oil sales can become significant. Figure 2-1 shows the Centech centrifuge during a field test at the Hobbs, New Mexico site.

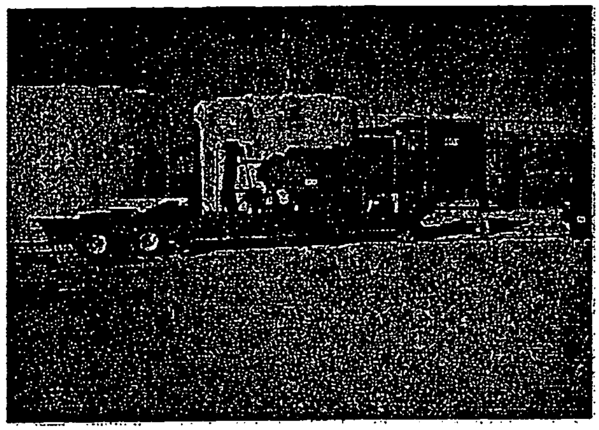


Figure 2-1. The Centech centrifuge on site in Hobbs, NM.

Figure 2-2 shows the centrifuge internals. The centrifuge consists of a spinning bowl that creates the centrifugal force that in turn provides the separation. This bowl is outlined in black and includes both the cylindrical and the conical sections of the centrifuge. The inlet components are separated by density (by centrifugal force) with the solid (shown as the dark colored phase near the outside wall of the centrifuge) being the densest. The water (shown as the lighter phase in the middle) is the next in density. And the oil (shown as a dark phase near the auger) is the least dense. The fluted cylinder in the center of the centrifuge is the auger. The feed mixture enters the centrifuge through ports on the auger, shown as two dark dots in the figure. The auger spins at a different rotation speed than the bowl, continuously expelling the clean solids from the centrifuge. Adjustable weirs control both liquid levels. The oil and the water are continuously being

removed from the centrifuge. Figure 2-3 shows the major components of the centrifuge system.

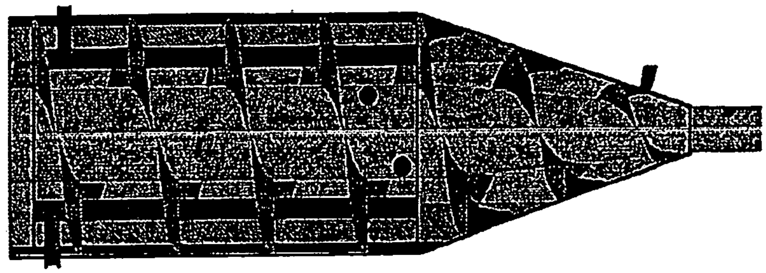


Figure 2-2. Centrifuge internals.

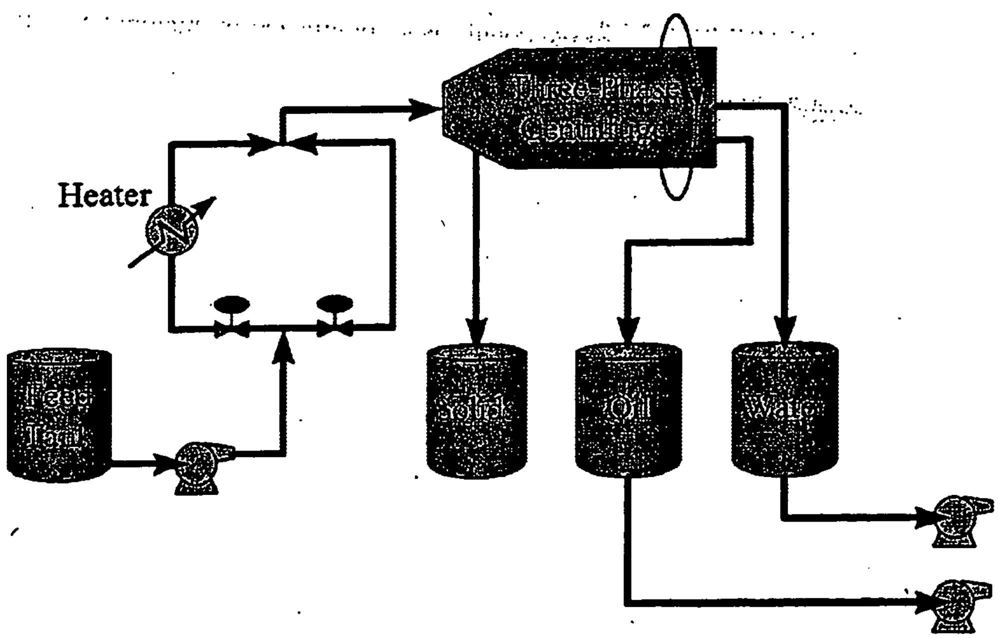


Figure 2-3. Schematic diagram of the centrifuge system.

The main components of the system are the centrifuge, the feed pump, feed heater, and product tanks. Sometimes a feed tank is included in the system, but often the feed is taken directly from waste pit or pond. The three controlled variables are the basic sediment and water (BS&W) in the product oil, the hydrocarbon content of the product water, and the hydrocarbon content of the product solid. The requirements for these variables vary from state to state, and sometimes even from site to site. For example, New Mexico requires the BS&W content of the oil to be 1% or less in order to be pipeline quality. Wyoming requires 0.3% or less. The major manipulated variables that affect this control are the feed pump speed, the feed temperature, the bowl speed, the auger speed, and sometimes dilution of the feed with product water. Unfortunately, the current version of the centrifuge requires that it be shut down in order to change the bowl speed. ~~At the present time most of the control is accomplished by manipulating the feed pump speed and the feed temperature.~~

Before Centech can offer this technology globally, at least one hurdle must be overcome. The expertise of the Centech personnel must be encapsulated into an intelligent setup and control system paradigm. The Centech centrifuge is a highly nonlinear multi-input, multi-output system. Tank bottoms and sludge differ from site-to-site and tank-to-tank, resulting in unique and varying control parameters for each material processed. Figure 2-4 shows a typical pit containing waste oil. This particular one is located in Hobbs, New Mexico. The 500-ft x 200-ft x 90-ft deep pit contains about one million barrels of oil that are tied up as an oil-water-solid emulsion. In many places this oil would be considered a hazardous waste, but after treatment by the centrifuge it will be saleable at the current market price.

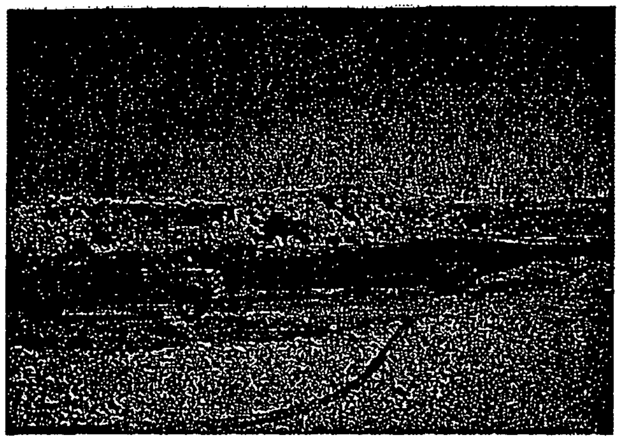


Figure 2-4. A typical waste oil pit.

In 1994, the Los Alamos National Laboratory team joined forces with Centech Inc. We designed and implemented a preliminary control system for the centrifuge based upon the expert knowledge of the Centech operators. The resulting expert based control system, through the implementation of fuzzy logic, controls the quality of the oil produced by manipulating only the throughput and temperature of the feed. We chose a fuzzy logic control system for two reasons:

1. Even though one objective of the original project was to develop a centrifuge model, the system proved too complex. The model that was developed was not adequate for control purposes.
2. It was entirely possible for an expert operator to maintain excellent control of the centrifuge system, under almost all circumstances. The expert's description of his control actions was almost identical to a textbook description of a fuzzy expert system.

Therefore, we chose to model the expert rather than the centrifuge, using a fuzzy expert system.

The product of the effort described in this work is a more advanced version of the original centrifuge control system. The new control system will be a feed-forward/feedback expert system that can be expanded to control multiple and remote systems. It will help Centech Inc. market its product globally by making it possible for a non-expert operator to operate the centrifuge effectively. Unfortunately, due to bad weather and multiple equipment failures, we have been unable up to this time to field test the feed-forward portion of the control system. Fortunately, the variables affecting the feed-forward portion of the control system can be modeled mathematically with a reasonable degree of accuracy. This has allowed us to build the fuzzy feed-forward system and test it against the computer simulation. The control system will have to be field tested and fine-tuned in the field at a future date.

2.3 THE ORIGINAL CONTROL SYSTEM

The original control system, or the feedback version of the new control system, is a fuzzy intelligent control system. The centrifuge and its peripheral equipment is a non-linear, time variant, multi-variable plant. Figure 2-3 is a schematic drawing of that plant, the Centech three-phase centrifuge system. The centrifuge is a continuous-decanting machine with a helical conveyor (sometimes called a scroll or auger). Spinning the feed mixture at high rpms creates a large centrifugal force and separates the three phases.

The control system is best described with an example. The rules and membership functions shown here. are similar to the ones that were obtained from the expert, but actual values are fictitious in order to protect Centech Inc.'s confidential information. All of the rules are in the system but currently only the rules regarding the BS&W in the

EXHIBIT B

AUTOMATICALLY CONTROLLED THREE-PHASE CENTRIFUGE AND METHOD FOR SEPARATING MULTI-PHASE MIXTURES

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to a centrifuge apparatus and more particularly to an improvement of a three-phase centrifuge especially adapted to a method for separating multi-phase mixtures including liquid and solid phase inorganic matter from organic matter.

Description of the Related Art

The three phase centrifuge separation technology disclosed in U.S. Patent 5,156,751 shows great promise for separating and extracting useful products from multi-phase mixtures of chemical waste and particularly petroleum waste. This technology has twin benefits of converting worthless waste into sellable products and reducing the environmental and economic costs of disposing of the waste. Unfortunately, product purity has proven difficult to control with this technology and centrifuge operators need considerable training and experience to separate waste products to high levels of purity. Uniformity of product purity is an especially serious problem in waste oil reclamation, and waste storage container cleanup where there are strict state and federal regulations on the levels of contaminants allowed in commercial oil.

A chief reason that product purity is difficult to control is that the multi-phase mixtures of waste materials are not homogeneous. A batch of waste oil, for example,

almost always contains pockets that are oil rich and contain relatively small amounts of basic sediment and water (hereafter called "BS&W") impurities. When these oil rich pockets, commonly called oil "slugs," are fed into the centrifuge, they imbalance the separation, and thus the product purity, by dramatically changing the relative amounts of oil, water and solids in the apparatus. In a typical situation, the sudden increase in the oil volume in the centrifuge pushes oil into product extraction tubes before it has had enough time to separate in the centrifuge from water and solids. Furthermore, the surge in oil volume in the centrifuge forces the oil layer into the water and solids layers of the separating mixture, thereby re-mixing the components.

One approach for better control of product purity in centrifuge technology has been to automate the control of the centrifuge apparatus. An automated control system can continuously monitor the mixture separation process and make quick adjustments to the centrifuge operating conditions in response to changes in product purity. Automating the operation of the centrifuge system also has an added benefit of reducing the training an expertise required by an operator to run the system. A major cost of current three-phase centrifuge separation systems that are currently disclosed arises from the need for a highly trained, very expensive expert operator to run the system. Automation solves this problem by alleviating tasks presently performed by the centrifuge operator and allocating those tasks to the automatic control system.

While the solution seems simple, implementation is problematic. Automated systems experience control difficulties in dealing with sudden changes in the relative composition of the mixture of the feed stock. For example, when an oil slug is fed into

the centrifuge, causing a sudden surge in oil volume, the automatic control system responds by driving the operating conditions in a direction that will maintain product purity. However, the control system typically overcompensates for the oil surge, driving the operating conditions so far from optimal that product purity is further diminished. This "pendulum" phenomenon of automated systems has made previous attempts at automation undesirable.

SUMMARY OF THE INVENTION

The present invention relates to a method and apparatus for separating multi-phase mixtures having a solid phase component, a higher specific gravity liquid phase component, and a lower specific gravity liquid phase component by employing a three-phase centrifuge. The present invention includes a number of mechanical improvements over the prior art that minimizes the changes in product purity during large changes in the relative composition of the mixture entering the centrifuge. Moderating the sudden, unpredictable changes in centrifuge operating conditions that are caused by changes in the mixture composition makes the present invention more adaptable to automated control. A preferred aspect of the present invention is interfacing the instant apparatus with an automated control system based on fuzzy logic to allow an operator with minimal training and expertise to run the centrifuge system.

The apparatus of the present invention contemplates a three phase-centrifuge for separating a multi-phase mixture comprising a horizontally mounted rotatable bowl that spins a multi-phase mixture to spatially separate the individual phases, such as a higher specific gravity liquid phase, a lower specific gravity liquid phase, and a solids phase.

In accordance with a preferred aspect, the higher specific gravity liquid phase component is water, and the lower specific gravity phase component an organic liquid phase. In the rotatable bowl, the liquid phases divide into separate pools within the bowl and the solid particles are thrown outward towards inner wall of the bowl by centrifugal force. A conveyor auger inside the rotatable bowl contacts the separated solid particles and sweeps them to a discharge area where they exit the bowl as higher specific gravity liquid phase component wet solids. A lower specific gravity phase component, also called a "pool," is contained between two baffles that are mounted on the conveyor auger. lower specific gravity phase material from the separated lower specific gravity phase material pool exits the rotatable bowl by a discharge means that includes lower specific gravity phase matter extraction tubes located within the bowl. Higher specific gravity liquid phase found in a separated higher specific gravity liquid phase pool in the rotatable bowl exits by a discharge means that preferably includes an adjustable weir to draw the separated higher specific gravity liquid phase into a higher specific gravity liquid phase discharge conduit.

A preferred aspect of the present invention includes a generally cylindrical shaped rotatable bowl having at least a 24 inch length and at least a 10 inch diameter.

Another preferred aspect of the present invention is to include at least one opening in the cylinder of the conveyor auger to allow the lower specific gravity phase to flow into the center portion of the centrifuge rather than being forced outward towards the higher specific gravity phase and solid phase portions of the separating mixture. The opening prevents the sudden swelling of lower specific gravity phase from pushing into the higher specific gravity phase and solids layers, thereby contaminating

all three layers. Allowing excess organic material flow towards the center also allows the present invention to run at deeper pool depths for the organic phase thereby permitting organic phase products to remain in the centrifuge longer and have higher purity.

Another preferred aspect of the present invention is to include at least one additional baffle in the centrifuge apparatus that minimizes abrupt changes in the purity of the extracted organic products by slowing the rate at which the organic matter flows to the organic phase extraction tubes and gets removed from the centrifuge. By hindering the flow of the organic phase product to the extraction tubes during sudden increases in the influx of organic phase materials, centrifuge retention times for these materials remain relatively constant, thereby keeping the purity level of the extracted products constant.

Still another preferred aspect of the present invention is an automated control system based on fuzzy logic that is used to replace many of the functions performed by an expert operator past systems. Considerable time and effort are needed to train someone to operate an non-automated three-phase centrifuge system. In this preferred aspect of the present invention, an automated controller makes the instant apparatus much simpler to operate and new operators can be trained in much less time. The automated control system is preferably based on a fuzzy logic design that automates the control of complex, nonlinear, multi-variable separation processes that depend on expert knowledge.

More specifically, the fuzzy logic based automated control system is adaptable to monitor wide array of properties in the raw material mixtures entering the centrifuge including, but not limited to, the volumetric percentages of solids, low specific gravity liquid phase components (such as organics) and higher specific gravity liquid phase components (such as water) in the mixture as well as the viscosity of these phases. The system may also adjust a large number of parameters including, but not limited to, the full speed, the rpm of the centrifuge and conveyer auger, heater temperature, and raw material flow rates into and out of the centrifuge. Simultaneous monitoring and adjustment of all these parameters by the operator is extremely difficult and requires extensive training. The automated control system of the present invention greatly reduces, if not altogether eliminates, the potential for operator error by having an automated "expert" analyze the complex processes and make split second adjustments that are necessary to keep the centrifuge operating properly while processing raw materials.

In addition to the cost savings realized by not having to employ and expensive expert operator, this preferred aspect of the present invention also reduces maintenance costs on the physical apparatus by almost always running the invention under optimal operating conditions. In contrast, a non-automated centrifuge, lacking the continuous dynamic feedback control system of non-linear operators, only provides intermittent monitoring of the apparatus (i.e., analog) and reduces the percentage of time the apparatus runs under optimum conditions. Consequently, parts must be repaired and replaced with greater frequency, and the system stays off-line for longer periods of time.

The automated control system, also offers the possibility of remote control to provide a safer environment for the operator and an increased ability to treat waste posing a higher level of health and environmental risk. This is particularly when the present invention processes toxic or volatile materials. Remote operation is achieved through sensor and actuator systems on the apparatus that are connected to the fuzzy logic controller, allowing remote operation that does not require the physical presence of the operator at the apparatus. Moreover, reprogramming the fuzzy logic controller for new sets of optimization parameters can also be done remotely.

The present invention also contemplates a process of separating multi-phase mixtures using a three-phase centrifuge. In a preferred aspect of the invention, where waste oil is the lower specific gravity phase component, and water is the higher specific gravity phase component, the instant process preferably includes the steps of: utilizing a mathematical model to calculate the initial operating parameters for the centrifuge; monitoring the basic sediment and water content (BS&W) and simultaneously controlling heater temperature and feed pump rate with an automated control system that is connected to the computer logic. More specifically, preferred aspects of the instant method include automating the steps of: agitating a mixture; heating the mixture to a selected temperature; introducing the heated mixture at a selected flow rate to a rotatable bowl; centrifuging the mixture at variable centrifuge speeds in the rotatable bowl to separate the water, the organic matter and the solid particles of the mixture so that different discharge means within the rotatable bowl can draw the separated liquids (organic and water) into separate discharge conduits; and conveying the solids out of the rotatable bowl as water wet solids, yet free from organic matter.

The apparatus and method of the present invention are contemplated for a wide variety waste remediation applications including animal waste remediation, toxic and volatile organic waste remediation, and biological waste remediation. It is also contemplated that the present invention can be used to purify and refine many kinds of solid inorganic products like, phosphates, carbonates and others inorganic salts an minerals.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a schematic diagram showing a method for separating components, such as, water, solids and organic matter in a mixture consistent with the present invention;

FIGURES 2 and 2A are schematic views of the present invention showing the separation of a mixture into its respective components by centrifugal force;

FIG. 3 is a perspective view of an apparatus constructed in accordance with the present invention for carrying out the method of the present invention;

FIGURE 4 is a schematic diagram of the present invention showing the relative movement of its parts and the movement of separated mixture components, such as, organic matter, water and solids through the centrifuge;

FIGURE 5 is a cross section taken through a centrifuge constructed in accordance with the present invention;

FIGURE 6 is an end view of FIG. 5 showing construction and location of water weirs for the centrifuge;

FIGURE 7 is a graph that shows the progress of the control input parameters for Example 2 below;

FIGURE 8 is a graph of the progress of the rules and controls output parameters for Example 2 below;

FIGURE 9 is a graph of the progress of the rules results for Example 2; and

FIGURE 10 is a graph that shows the progress of product oil BS&W as a function of time in an actual run for Example 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The terms "mixture" or "multi-phase mixture" used herein refer to combinations of two or more substances in which each substance retains its own composition and properties. In a preferred aspect, frequently cited herein, the multi-phase mixture to be separated comprises a solids phase, a higher specific gravity liquid phase component, like water, and a lower specific gravity liquid phase component, like waste oil. In a typical example described herein, the process of the present invention is used to separate solids, water and oil which are then used, sold or safely disposed.

In a preferred aspect of the present invention, a mathematical model provides the initial operating parameters for the separation process. The model is based on an extension of the so-called "sigma theory" for the separation of two-phase mixtures. Sigma theory models the operational behavior of the present invention based on data collected from other centrifuges. The theory helps determine which factors have the greatest affect on the separation of the original, multi-phase feed mixture. As feed mixtures vary considerably, this model helps an operator to properly set apparatus

parameters such as temperature, feed rate, weir height, organic pool depth, initial residence time, initial bowl speed and initial conveyor speed.

In another preferred aspect of the present invention, an automated control system runs on a portable computer and assimilates an "intelligent" fuzzy controller designed to replicate human expertise in operating the centrifuge. LabWindows is used for a user-friendly interface and is integrated with fuzzy logic software by writing code in C. The automated control system is based on artificial intelligence (for the analysis of expert judgement), fuzzy logic, and feedback control theory, and it automates the control of the nonlinear, time-variant, and multi-variable process of multi-phase mixture separation.

A preferred aspect of the present invention for reclaiming contaminated oil by the process of the present invention, includes a set of rules that were developed for the fuzzy controller based on the vast operational experience of the inventor of the original invention. The rules set controls the BS&W content in the organic (i.e., oil) product and as well as the oil content in the water product. The fuzzy controller monitors the BS&W content in the organic product and then uses the rule set to determine what adjustments to make in the feed rate and feed temperature of the waste materials entering the centrifuge. In this preferred aspect of the invention, a set of 16 rules are used to control the BS&W content of the oil product:

1. IF the BS&W is Very High (VH) AND the Oil in Water is High (H) THEN The Feed Rate Change is Negative Big (NB).
2. IF the BS&W is Very High (VH) AND the Oil in Water is OK THEN The Feed Rate Change is Negative Big (NB).

3. IF the BS&W is High (H) AND the Oil in Water is High (H) THEN The Feed Rate Change is Negative Big (NB).
4. IF the BS&W is High (H) AND the Oil in Water is OK THEN The Feed Rate Change is Negative Small (NS).
5. IF the BS&W is OK AND the Oil in Water is High (H) THEN The Feed Rate Change is Negative Small (NS).
6. IF the BS&W is OK AND the Oil in Water is OK THEN The Feed Rate Change is Zero (Z).
7. IF the BS&W is Low (L) AND the Oil in Water is High (H) THEN The Feed Rate Change is Zero (Z).
8. IF the BS&W is Low (L) AND the Oil in Water is OK THEN The Feed Rate Change is Positive Small (PS).
9. IF the BS&W is Very High (VH) AND the Oil in Water is High (H) THEN The Feed Temperature Change is Positive Big (PB).
10. IF the BS&W is Very High (VH) AND the Oil in Water is OK THEN The Feed Temperature Change is Positive Big (PB).
11. IF the BS&W is High (H) AND the Oil in Water is High (H) THEN The Feed Temperature Change is Positive Big (PB).
12. IF the BS&W is High (H) AND the Oil in Water is OK THEN The Feed Temperature Change is Positive Small (PS).
13. IF the BS&W is OK AND the Oil in Water is High (H) THEN The Feed Temperature Change is Positive Small (PS).
14. IF the BS&W is OK AND the Oil in Water is OK THEN The Feed Temperature Change is Zero (Z).
15. IF the BS&W is Low (L) AND the Oil in Water is High (H) THEN The Feed Temperature Change is Zero (Z).
16. IF the BS&W is Low (L) AND the Oil in Water is OK THEN The Feed Temperature Change is Negative Small (NS).

Each variable in the rules listed above are associated with a particular membership function. The following membership functions are used:
For BS&W, an input variable, the membership functions are Low (L), OK, High (H), and Very High (VH).
For the percent oil in water product variable, only two membership functions, OK and High (H) are used here.
For the output (i.e., manipulated) variables Feed Rate Change and Feed Temperature Change, five membership functions were used for each, and they have the same labels: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB).

The BS&W input value reflects a voltage generated by a BS&W sensor that represents the BS&W content of the separated organic matter. The fuzzy controller uses the rules to calculate membership functions for the output variables based of the

BS&W's membership function that is calculated from the BS&W sensor voltage. Once the expert-defined fuzzy rules are activated, their result is then de-fuzzied and converted into numerical values or voltages that control the speed of the feed pump 12 for an optimal feed rate and the heater 16 for optimal feed temperature.

If semantic limits on input variables are ignored, the automated control system does not function adequately. Moreover, the limits and membership functions (that is, the numerical descriptions of the linguistic concepts) often vary according to the task performed by the centrifuge. An innovative adaptive feature of the automated control system allows the operator to change limits and membership functions, as necessary. The operator can also change multiple variables simultaneously rather than in series. This improvement results in less time and money spent on a particular task. Finally, the controller monitors the complex mixture separation process continuously and keeps the centrifuge in an optimal operating range.

Prior to operation, a mathematical model is preferably used to set centrifuge parameters such as weir height, pool depth, initial residence time, initial bowl speed and initial conveyor speed.

A preferred aspect of the invention is shown in FIGS. 1-10, described below. In this illustrated embodiment of the present invention, the multi-phase mixture comprises water as the higher specific gravity liquid phase component, organic matter, such as oil, as the lower specific gravity liquid phase component, and a solids phase.

Referring now to FIG. 1 a method of processing a mixture in accordance with the present invention is shown. As a first step a mixture is collected in a receptacle such as a feed tank 10. Prior to processing a mixture, it may be analyzed to determine its

content. As an example, a sample may be analyzed to ascertain the percentages of solids, water (the higher specific gravity phase component) and organic matter (the lower specific gravity phase component) in the mixture. The temperature of a sought after product as well as its chemical composition may also be determined. This information may then be utilized to select the process parameters for processing the mixture in accordance with a preferred method of the present invention.

Some contaminated mixtures are preferably stirred or otherwise agitated to provide a more homogeneous mixture. This may be done by mechanical stirring or by bubbling compressed air or inert gases through the mixture. It may also be desirable to remove large solid objects such as rocks and vegetation from the mixture.

Agitation is preferred, for example, to mix any organic matter and water in the mixture to provide a more constant organic matter-to-water ratio to feed into the centrifuge 14. Also, a mixture may contain solids concentrated in an organic matter and mixing more evenly disperses these solids through the mixture.

From the feed tank 10 the mixture is pumped through suitable conduits by a feed pump 12 through a heater into a centrifuge 14 constructed in accordance with the present invention. The feed pump 12 may be selected to maintain a desired flow rate for the mixture.

Additionally, the feed pump 12 which is preferably a variable volume pump controlled by the computer logic in accordance with the invention, may be selected to pump the mixture with a minimum of turbulence. A contaminated product may contain relatively large solid particles that are more efficiently removed from a mixture if they remain unbroken. Breaking solid particles increases the total surface area of the solids

within the mixture and promotes adherence of these smaller solids to any organic matter within the mixture. It is therefore desirable to maintain large solid particle sizes. Suitable control means may be operably coupled to the feed pump 12 to achieve a selected output from the feed pump 12. Feed rates to the centrifuge 14 may vary depending on the type of mixture being processed and on the rated capacity of the centrifuge 14. In an illustrative example of the present invention feed rates may be varied from about 15 gallons per minute (GPM) to a maximum of about 65 gallons per minute (GPM). In the present invention, there is also a manifold for the feed pump 12 which will enable an operator to by-pass the heater 16 and the centrifuge 14.

In a preferred aspect of the present invention, panefolds are provided to selectively bypass particular operations within the system. For example, in accordance with one aspect, the heater 16 can be bypassed and no further heat is necessary to activate to decrease the viscosity of the feed mixture. Likewise, manifold is provided that will bypass centrifuge 14 in accordance with the invention, thereby allowing heated fluid to pass directly through to be retained in the catch tanks and then re-circulated back to the feed tank in order to reduce the viscosity of the feed mixture communicating with the feed pump. In accordance with this aspect of the invention, preferably used in the start up phase of the separation operation, no product is produced, since all materials emerging either from the heater or the centrifuge are recycled back into the feed tank until system conditions are stabilized. Several types of heaters can be used in this process, preferably one selected from the group consisting of an in light heater, an emergent heater, and a filament heater.

Another preferred aspect of the invention includes a separate chamber located inside a perforated cylinder of the present invention to counteract the variations in the ratio of organic matter-to-water that inevitably occurs as the mixture is fed into the centrifuge 14. The perforated cylinder is a cylinder comprising at least one opening to allow liquids to enter a center portion of the centrifuge. Among other things, such variations may disrupt the seal which forms between the organic matter pool and the water pool, decreasing the discharge rates of the separated materials.

In another preferred aspect of the present invention a feed pump 12 may be controlled to maintain a smooth even flow of mixture to the centrifuge 14 in order to minimize the mixing of the solid particles within the organic matter. This may increase the separation efficiency of the centrifuge 14 by decreasing the mixing between the organic and water pools formed within the centrifuge 14. The feed pump 12 is preferably driven by an electric motor and controller 13 (FIG. 4). The speed of the electric motor may be controlled with a suitable motor controller so that the pump rate can be accurately controlled. This control can be used to fine tune the process and maintain steady operation of the centrifuge 14.

In yet another preferred aspect of the present invention the multi-phase mixture is heated with a heater 16. Heating the mixture decreases its viscosity, allowing it to move more easily through the centrifuge 14. Heating may also change other properties of particular kinds of mixtures to make them easier to separate in the centrifuge 14. Heated mixtures preferably have a temperature range from about 100°F to about 250°F, more preferably from about 125°F to about 200°F.

In a preferred configuration of the apparatus of the instant invention, the mixture is moved by the feed pump 12, through the heater 16, and then into the centrifuge 14. As shown schematically in FIG. 2 and 2A the centrifuge 14 includes a horizontally mounted rotatable bowl 18 that spins about its longitudinal axis. The rotation speed of the rotatable bowl 18 (measured in rpm's) preferably ranges from about 900 RPM to about 2000 RPM, more preferably from 1500 RPM to 1800 RPM, and even more preferably from about 1750 RPM to 1800 RPM.

In another preferred configuration of the apparatus of the instant invention, the length of the centrifuge 14 is preferably at least 24 inches, increasing the centrifuge's 14 mixture capacity. Furthermore, the centrifuge 14 has a preferred diameter of at least 24 inches, more preferably between about 24 inches and about 30 inches. Increasing the diameter of the centrifuge 14 to the preferred size increases the g-forces on the mixture in the centrifuge 14 for a given rotation speed of the rotatable bowl 18 and enhances the overall separation efficiency of the apparatus of the instant invention. Increasing the diameter of the centrifuge 14 also increases the volume of mixture that it can hold. Under preferred operating conditions, the instant invention subjects the mixture, which includes solid particles 20, to acceleration forces preferably between about 700 g's to about 1000 g's. Applying these high g-forces to the solid particles 20 accelerates them radially outward towards the inside wall of the rotatable bowl 18 where they are conveyed away by a conveyor auger 22 (FIG. 4).

The mixture inlets of the present invention are preferably fitted with nozzles to direct the mixture as it enters into the inlet port 70. Additionally, three-sided baffles are preferably fixed to the mixture inlets. These inlet modifications enable an operator to

direct the flow of the incoming mixture into the centrifuge 14 so as to minimize the disruption of the organic matter and water pools, when water is the higher specific gravity phase component and organic matter (such as oil) is the lower specific gravity phase component. The resultant increase in control also enhances the overall operating efficiency.

As shown schematically in FIG. 2 and FIG. 2A, rotation of the rotatable bowl 18 creates a separate pool of water 24 and organic matter 26 that have different depths within the rotatable bowl 18. These separate pool depths of water 24 and organic matter 26 occur because the water (a highly polar liquid) and the organic matter (usually non-polar) do not form one homogeneous liquid phase. Moreover, water and organic matter usually have different specific gravities, allowing them to be separated by the large centrifugal forces exerted by the rotatable bowl 18. Because water and organics are practically immiscible with each other, an emulsion of the two liquids under high g-forces will quickly separate into a water and an organic phase. The phases form two layers (i.e., pools) on top of one another in the centrifuge, and each layer has a thickness or depth (called the pool depth). Contamination of one phase by the other is greatest at the boundary between the pools, and least at locations in each pool that are farthest away from the boundary.

In a preferred aspect of the present invention, the pool depth between the water and organic phase in the centrifuge is increased to provide purer separation products. Since the purity of the separated water and organic materials increases with increasing distance from the boundary between the two phases, deeper pools provide purer products at pool locations which are furthest away from the phase boundary.

Moreover, deeper pools allow the liquids of the mixture to stay longer in the centrifuge 14. Giving the water, solid and organic phases more time to separate from one another in the centrifuge 14 also increases the purity of the extracted products.

In accordance with this preferred aspect of the present invention, greater liquid pool depths are created by reducing the diameter a cylinder element of the conveyor auger 22 (see FIG. 4), and positioning slotted plates 114 (see FIG. 6) over the weirs 84 such that liquid product is removed from the centrifuge 14 only after the pool of that product reaches a particular depth and spills over the slotted plate 114 into the weir 84.

In another preferred aspect of the instant invention, the baffle plates 76, 77, 127 are increased in length in proportion to the diameter of the centrifuge 14 and the conveyor auger 22 to increase the depth of the organic pool that is held between the baffle plates 76, 77, and 127. Increasing the length of the baffle plates 76, 77 and 127, increases the depth of the organic pool and the time the organic product stays in the centrifuge 14, thereby increasing the purity of the organic product that is extracted from centrifuge 14. Also, the slotted plates 114 that partially cover the weirs 84 are preferably moved towards the center axis of the rotatable bowl 18 further increasing the retention time and pool depth of the separated liquid layers.

In another preferred aspect of the instant invention, at least three baffles 76, 77, 127 sandwich the organic matter pool 26. The baffle plates are further modified in proportion to the length and diameter changes to the centrifuge, cited above, and baffle plate 127 contains at least one opening 128 to allow liquid to flow through the plate 127. These modifications allow the segregated organic pool to form upon separation among the baffles and result in a greater retention time of the organic pool.

As will hereinafter be more fully explained, separate discharge means, water discharge means 27 and organic matter discharge means 29 within the rotatable bowl 18, remove the water and organic matter from the centrifuge 14 at different pool depths within the centrifuge 14. Moreover, as previously stated, the conveyor auger 22 (FIG. 4) conveys the solids out of the centrifuge 14. A sensing and control means 33 regulates the speed of the conveyor auger 22 and the output of solids in response to the 20 amount of solids in the mixture.

With reference to FIG. 1, discharge of the solids from the centrifuge 14 is represented by arrow 28, discharge of organic matter is represented by arrow 30 and discharge of water represented by arrow 32.

The liquid organic matter and water discharged from the centrifuge 14 may be gathered in suitable receivers (organic matter receiver 34, water receiver 36). The organic matter may then be pumped through suitable conduits by a pump 38 to a storage vessel 56. 58 (FIG. 3). The water 36 may be pumped away by a water pump 40. Additionally, as shown schematically in FIG. 1. some water is preferably pumped through conduits by a makeup pump 46 back into the centrifuge 14. This make-up water facilitates separation of the solids and the organic matter within the mixture for some kinds of mixtures. The present invention preferably has a discharge manifold built to utilize the pumps from either the organic matter or water receivers to the storage vessel.

Referring now to FIG. 3, the apparatus of the present invention is shown in an illustrative embodiment. As shown the apparatus includes the centrifuge 14, feed pump 12 and heater 16, all mounted on a movable trailer bed 48. The trailer bed 48 may be

transported by a truck in order to move and perform the method of the present invention at different job sites. The centrifuge is mounted on a frame 49 or a stand located on the trailer bed 48.

In a preferred aspect of the present invention, a trailer bed 48 of the present invention is a low-boy type with an extended top deck to accommodate a larger control house. The trailer bed 48 also has a sump pump built into its interior to handle any spills, snow melt, rain or other leaks that may occur. This modification improves the invention's overall environmental acceptability. Further, leveling jacks are built into the trailer bed 48 along with hose packs for easier set-up.

All power cables, including those for the centrifuge, the pumps and the lighting system are directed into a hidden and sealed power cable storage means which is built into the trailer bed 48. Additionally, all mounts for components, such as, the pumps, the heaters and the centrifuge are incorporated into the main supports and bracing of the trailer bed 48. This modification will minimize the total weight of the present invention. Also, the centrifuge stand is telescoping and the sump pump is set-up to transfer fluids. Finally, the trailer bed 48 is modified to include an air ride suspension system to minimize the vibrational motion to which the component systems may otherwise be subjected.

An operator enclosure 50 is mounted at an elevated end of the trailer bed 48. The operator enclosure contains various control means which enable an operator to control different parameters of the process (i.e. feed rate, temperature, discharge, continuity). The operator enclosure 50 provides an operator protection from the elements and preferably includes one or more viewing windows 52. The operator

enclosure 50 of the present invention is preferably at least twice the size of the original invention. The modified operator enclosure 50 is also preferably heated and air conditioned in order to maintain a controllable operating environment for the control systems located within the operator enclosure 50 and for the operator.

The hydraulic back drive may be mounted near the operator enclosure 50. The hydraulic back drive of the present invention is constructed to match the size of the rotatable bowl 18 and the conveyor auger 22. Further, a hydraulic pump may be mounted remotely and be fitted with a heavy duty air cooling unit.

The present invention may include a utility shed mounted to the trailer bed 48. The utility shed could be used to store spare parts and to house support and safety equipment. It may even include a small work bench, a number of lockers and a small lab area.

A mixture to be processed is contained in an mixture 55 storage tank 42. As previously explained, the mixture may be agitated or stirred within the storage tank 42. The feed pump 12 receives the mixture though suitable conduits (not shown) from the storage tank 42 and moves the mixture through the heaters 16 (as required) and into the centrifuge 14. A solids discharge chute 54 receives the processed water wet solids from the centrifuge 14. Storage tanks 56, 58 receive through suitable conduits (not shown) the separated organic matter from the centrifuge 14.

Referring now to FIG. 4 a schematic of the centrifuge 14 is shown. The centrifuge 14 includes the rotatable bowl 18 and the conveyor auger 22. Mixture is pumped by the feed pump 12 through the center of the conveyor auger 22 and into the rotatable bowl 18. Rotation of the rotatable bowl 18 separates the mixture into the

organic matter, water and solids. The solids are pushed as indicated by arrow 116 by the conveyor auger 22 to a solids discharge port 68. The organic matter and water separated by centrifugal forces along a line of separation 82 are discharged at a fluid discharge end 78 of the rotatable bowl 18. The organic matter is discharged from the organic matter discharge tubes 80 located at a pool depth to contact only organic matter. Water is discharged from water weirs 84 located at a pool depth to contact only water.

In an illustrative embodiment of the present invention the rotatable bowl 18 rotates about a longitudinal axis 60 in a clockwise direction as indicated by arrow 62. Suitable drive means such as an electric drive motor (not shown) may be drivably coupled to the rotatable bowl 18 to power the rotation.

The rotatable bowl 18 is hollow and generally cylindrical in shape but is formed with a tapered beach 64 of reduced cross section at one end. As will hereinafter be more fully explained, the tapered beach 64 provides an annulus of reduced cross section which during operation of the centrifuge fills partially with water. Also, in light of the centrifuge length modifications referenced above, the beach angle and clearance is changed to convey lighter solids under higher g-forces.

In the present invention, the inlet port 70 is set back from the beach more than in the original invention due to the increased mixture volume entering the centrifuge at the point where fine solids are trying to separate and to be conveyed out of the centrifuge. The purpose of this modification is to reduce the regulation necessary between the liquid and solid phases.

The beach 64 of the rotatable bowl 18 may be lined with a smooth non-porous material such as ceramic tiles. This smooth surface provides reduced friction for solids that are pushed by the conveyor auger 22 through the beach 64 and out the solids discharge port 68. Also, caked solids that form after a period of "shut down" are more easily separated from the beach 64 comprising a smooth surface.

The centrifuge 14 also includes the conveyor auger 22 that is concentrically mounted within the rotatable bowl 18 and is also journaled for rotation. In an illustrative embodiment of the present invention, this direction of rotation of the conveyor auger 22 is opposite to the direction of rotation of the rotatable bowl 18 and is counterclockwise as indicated by arrow 66. Alternately, both the rotatable bowl 18 and the conveyor auger 22 may rotate in the same direction.

In accordance with the above mentioned centrifuge length and diameter changes of the present invention, the conveyer auger's 22 length and diameter are correspondingly modified to match those of the centrifuge. However, the conveyer auger 22 maintains the close tolerances between its flights 74 (described further below) and the rotatable bowl 18.

The conveyor auger 22 may be driven by a suitable drive means such as a hydraulic drive motor 31 (FIG. 3). The rotational speed of the hydraulic drive motor 31 may be closely controlled by suitable sensing and control means 33 (FIG. 1) responsive to the amount of solids being conveyed to the discharge port 68. A sensing and control means 33 may be utilized, for instance, that senses a hydraulic drive pressure on the hydraulic drive motor 31. This pressure may then be related to the

torque on the conveyor auger 22 exerted by the solids being conveyed. With the sensing and control means 33 an increase in pressure and in the torque caused by an increased amount of solid particles within the rotatable bowl 18 can be sensed and the conveyor auger 22 speed may be increased to handle the increased load. Jams and slugs of solid material can thus be cleared in this way to insure a constant flow of solids through the rotatable bowl 18 and discharge of solid material through the discharge port 68.

The conveyor auger 22 is generally cylindrical in shape and is hollow in the middle. The conveyor auger 22 includes an inlet port 70 for the contaminated mixture and a plurality of mixture inlets 72 that discharge the mixture into the rotatable bowl 18. In an illustrative embodiment of the present invention the mixture is discharged into the rotatable bowl 18 with a flow direction towards the fluids discharge end 78 of the rotatable bowl. This is termed a co-current inlet flow. Alternately, the centrifuge may be configured with a counter current inlet flow.

The conveyor auger 22 is formed with helically wound flights 74 on its outer periphery. These helical flights 74 move the solids that are pushed by centrifugal force against the inside of the rotatable bowl 18 through the rotatable bowl 18 and to the solids discharge port. In light of above mentioned modifications to the present invention, twin lead flights are added to handle the increased volume of finer solids generated by the finer cut on the liquid phases. This can also be achieved by changing flight angles and increasing the number of flights per inch in the beach area.

The center of the conveyor auger 22 forms an auger drum. In the present invention the auger drum is as small as possible. This modification allows for taller

flights 74 on the conveyor auger 22 which in turn enables deeper liquid phase pools to be formed. The modified auger drum preferably has at least one opening 129 to allow previously dead space to be utilized for an organic phase buffer zone. This also enables the organic matter discharge tubes to be run closer to center of the rotatable bowl 18 and to accept larger percentage changes in the volume of the organic phase without flooding the organic matter pool formed among the baffles. 76, 77, 127. Organic matter can migrate in and out of the organic phase buffer zone as needed without affecting the organic matter pool. This also provides for greater retention time, which in turn produces a cleaner separated organic phase. Further, this modification also prevents the organic phase from flooding over the baffles 76, 77, 127 into the water pool beach area.

As previously stated, in an illustrative embodiment of the invention the conveyor auger 22 turns in an opposite direction (CCW) than the rotatable bowl 18 (CW). Alternately the conveyor auger 22 may be configured however, to turn in the same direction as the rotatable 15 bowl 18, as long as it has flights 74 shaped to move solid material to the discharge port 68.

As an example, the conveyor auger 22 preferably turns at from one to twelve revolutions per minute with respect to the rotatable bowl 18. If the rotatable bowl 18 is turning for example at 1780 rpm the conveyor auger 22 must turn at this rate plus one to twelve rpm's more. This rate is termed herein as the conveyor augur ratio and in general is a number between one and twelve.

In a preferred aspect of the instant invention, at least three baffle plates 76, 77, 127 are mounted on the conveyor auger 22 to maintain a pool of organic matter thereamong. A first baffle plate 76 is located adjacent to the mixture inlets 72 to the

rotatable bowl 18. A second baffle plate 77 is located adjacent the fluids discharge end 78 of the rotatable bowl 18. A third baffle plate 127 is located between the first and second baffle plates 76, 77 and comprises at least one opening 128 to allow liquid to flow through the baffle 127 when the organic pool reaches a particular depth. During operation of the centrifuge 14, the baffle plate 127 slows the rate at which the organic phase liquids 26 flow to the organic product extraction tubes 80, and extends the retention time for the products in the centrifuge 14.

Referring now to FIG. 5 the centrifuge 14 is shown in more detail in an actual cross section. As previously stated the centrifuge 14 includes the rotatable bowl 18 and the conveyor auger 22. Additionally the entire assembly is enclosed by a stationary enclosure 86.

The stationary enclosure 86 includes a solids discharge pan 88 that receives solids discharged from the solids discharge port 68. Due to the referenced beach angle modification and the conveyor auger 22 changes which result in increased pool depth, the solids discharge port is moved from the end of the present centrifuge to its side. The stationary enclosure 86 also includes an organic matter discharge section 90 for receiving organic matter thrown out of the organic matter discharge tubes 80. The organic matter discharge section 90 of the stationary enclosure 86 terminates in a threaded coupling 92 that may be coupled to suitable conduits for pumping the processed organic matter into the storage tanks 56, 58 (FIG. 3).

Another preferred aspect of the instant invention includes button-type drain storage tanks. The modified storage tanks are preferably covered with hinged lids for collecting samples.

The stationary enclosure 86 also includes a water discharge section 94 for receiving water discharged from the weirs 84. The water discharge section 94 terminates in a threaded coupling 96. This coupling 96 is preferably coupled to suitable conduits for pumping the water away or back into the centrifuge 14 to aid in processing some mixtures. An air space 79 is formed between the water discharge section 94 and organic matter discharge section 90. To prevent condensation from forming in this region of the present invention, a specially machined seal preferably made of Teflon or Viton is preferably utilized in addition to a small vacuum for the vapor recovery system. The air space 79 is also changed to ensure that no mixing occurs between the organic and water phases.

In the present invention, the organic matter, water and solids discharge "cases" may be "tightened up" using Teflon sheeting machined to fit the contour of the rotatable bowl 18. The liquid "cases" may also be vented to ensure minimum "case" pressure and a smoother flow of the discharge liquids.

The rotatable bowl 18 is journaled for rotation on heavy bearings 98 which will be mounted on pillow blocks (not shown) on a stationary framework. In the present invention, such bearings, in addition to all "cases", covers, plumbing components, high temperature seals and bushings may be constructed out of stainless steel. Alternatively, they may be constructed of Viton or Teflon. The plumbing components may also be insulated to prevent heat loss.

A drive sheave 100 is drivably coupled to an electric drive motor for turning the rotatable bowl 18. A thrust bearing 126 is mounted on an opposite end from the drive

sheave 100. The hollow cylindrical conveyor auger 22 is mounted on a stationary hollow trunion 118 and is journaled on sleeve bearings I02,104 for rotation within the rotatable bowl 18. Suitable seal elements 120, 122 seal the conveyor auger 22 from the rotatable bowl 18 and stationary enclosure 86. Other seal elements 124 seal the rotatable bowl 18 at the fluid's discharge end 78. The conveyor auger 22 is coupled to a splined shaft 106 that drivably couples to a hydraulic drive.

The present invention preferably includes motor controllers for controlling the feed pump, the centrifuge and the discharge pumps. Also, heater controls may be changed to a digital key pad-type thermostat. Further, all items such as breakers, motor controllers and transformers may be mounted in one main control panel and be controlled remotely from a small operator panel mounted so the operator can see all equipment clearly from a seated position within the operator enclosure.

The baffle plates 76, 77, 127 are attached to the conveyor auger 22. The baffle plates 76, 77, 127 are flat and generally circular in shape and are welded directly to the conveyor auger 22. The at least one middle baffle 127, comprises an opening to allow organic phase material 26 to flow through the baffle at a controlled rate. These baffle plates 76, 77, 127 are sized to confine the organic matter pool formed in the rotatable bowl 18 to retain organic matter between the mixture inlets 72 and the organic matter discharge tubes 80. This permits the organic matter discharge tubes 80 to draw only organic matter.

Water is also formed as a continuous pool 24 (see FIG. 2A) and extends into the beach area 64. In addition to being located adjacent to the organic matter pool 26, the

water pool 24 is located on an opposite side from the organic matter pool 26 at the front baffle plate 76. Additionally, at the liquid discharge end 78 of the rotatable bowl I8, the water pool 24 extends on the opposite side of baffle 77 from the organic matter pool 26. Additional baffle plates 108 may be welded over each of the four mixture inlets 72 that are formed on the conveyor auger 22. These baffle plates 108 function to keep mixture directed from the mixture inlets 22 into the rotatable bowl 18 from disrupting the separate liquid pools (organic matter 26 and water 24 [FIG. 2A]) formed within the rotatable bowl 18. It is critical throughout the construction and operation of the centrifuge 14 to provide for a smooth laminar flow of liquids through the centrifuge 14.

The flights 74 of the conveyor auger 22 are welded directly to the generally cylindrical exterior of the conveyor auger 22. The flights 74 are machined to an outside diameter that is just slightly less than the inside diameter of the rotatable bowl 18. This arrangement permits fine or water caked solid particles to be pushed by the edge of the flights 74 to the solids discharge port 68. As is apparent the flights 74 tend to push the solids mostly through the water pool 24 located along the inner wall of the rotatable bowl 18 and the water pool 24 formed in the beach area 64. This movement of solids through water helps to scrub the solid particles free of organic matter so that the discharged particles are water wet and not encapsulated with organic matter.

The organic matter discharge tubes 80 are mounted directly to the rotatable bowl 18. In an illustrative embodiment there are four organic matter discharge tubes 80, a set of two front tubes and a set of two back tubes. The front tubes are located farther into the interior of the rotatable bowl than the two back tubes which are located adjacent to the baffle plate 77. This axial offset is indicated by distance "X" in FIG. 5.

These two sets of axially offset organic matter discharge tubes 80 each function to draw organic matter from the organic matter pool 26 but at different axial points along the longitudinal axis 60 of the rotatable bowl 18. (As shown in FIG. 2A the organic matter pool 26 is formed in a semi-continuous pool 26 located among the baffle plate 76, 77, 127). The front organic matter discharge tubes tend to draw organic matter out in a pool area in front of the baffle plate 77 whereas the back tubes tend to draw organic product out at a pool area adjacent to the baffle plate 77. Because these two sets of organic matter discharge tubes 80 are located at different axial points in the organic matter pool 26 (FIG. 2A), the efficiency of organic matter discharge is improved and the discharge of water with the organic matter is decreased or eliminated.

Each organic matter discharge tube 80 is mounted on a threaded stud. This permits the tubes 80 to be located at an optimum depth within the organic matter pool 26 for drawing only organic matter from the pool. Alternatively, each of the organic matter discharge tubes may be placed at an optimum depth by means of precision ground notches that enable the tubes to be locked into pre-set positions. Discharge efficiency from the organic matter pool may also be enhanced by reconfiguring the end portions of the organic matter discharge tubes within the centrifuge to form elongated ellipsoids.

The weirs 84 for discharging preferably water from the centrifuge are located on a end plate 110 attached to the end of the rotatable bowl 18. As shown in FIG. 6 the end plate 110 has four generally rectangular shaped 10 openings 112 formed therethrough. Slotted plates 114 partially cover the openings 112. The location of these slotted plates 114 may be adjusted as required at a pool depth for withdrawing water from the rotatable bowl 18.

EXAMPLES

Example 1

A Mixture of Organic Matter/Water/Light Solids

Before processing any mixture, a sample of the mixture is first subjected to a laboratory centrifuge or "grind out" to ascertain its characteristics, including solids content, organic matter percentage, water percentage and chemical composition if necessary. This helps to determine the process parameters to be used in processing the mixture. Additionally the "grind out" rpm's and diameter of the lab centrifuge can be utilized to determine g-forces needed to process the mixture. In general, mixtures having a solids content of less than 30% are considered light solids.

Weir Setting

A light solids mixture requires a relatively deep water pool to insure constant and smooth flow of water through the centrifuge 14. This is done by moving the water weirs plates 114 towards the center of the centrifuge.

Organic Matter Tubes

With lighter types of organic matter in a mixture, the organic matter tubes 80 must be set radially inward to keep a deep pool of organic matter among the baffles plates 76, 77, 127. This gives more retention time in the centrifuge l4 and produces a better or optimal separation of organic matter, solids and water. This is necessary with mixtures containing lighter types of organic matter because relatively fine solids are often dispersed within the organic matter phase. Accordingly, more retention time within the centrifuge is required to separate these fine particles from the mixture. The initial setting of the organic matter tubes 80 may have to be changed after start up. This setting will depend on the percentage of organic matter in the mixture and the feed rate to the centrifuge 14.

Conveyor Auger

For all mixtures the conveyor ratio should be run as low a possible to keep agitation in the centrifuge 14 to a minimum. A good starting ratio is 2-3. This may have to be increased if solids are not conveying out of centrifuge 14 fast enough. Otherwise, the centrifuge 14 may load up with solids which are carried over into the liquids discharge.

Feeding Liquids

With organic matter and water it is easy to ascertain an optimal pool setting. As soon as organic matter and water pools form at the predetermined depths and liquid discharge occurs there should be an instant organic matter/water split. It will take some period of operation (e.g., 15 minutes) for the centrifuge to level out at this rate. The feed rate into the centrifuge can then be set to achieve maximum volume and an optimum separation of liquids and solids. Most types of organic matter can only be processed relative to their physical characteristics and solids content. Feed rates vary from, as an example, 15 GPM to a maximum of 60-65 GPM.

Agitation

Mixture agitation may be necessary to mix organic matter and water and to achieve a constant organic matter/water ratio feed to the centrifuge 14. Lighter organic matter may not need as much agitation as sulfur containing or heavier organic matter because finer solids tend to stay tied up in the liquid. This is called an inner phase. These solids are emulsified or coated and are dispersed in the liquids. Caution should be taken to not use too much agitation as the emulsification may worsen. This requires more retention time to make a clean split of the liquids and solids. If there is little or no water in the feed tank 42 it should only be mixed long enough to stir the solids off of the bottom of tank and keep the fluids moving smoothly through inlet hoses.

Temperature

In general, the processing temperature is usually a maximum that the organic matter contained in the mixture can take before the light end of the organic matter is cooked or burned. If cooking occurs, gases will be produced in the centrifuge. This will upset the pool depths in the centrifuge 14 and may rendered unacceptable organic matter and water discharges. If this occurs, the heaters 16 should be shut down until the liquid cools to its operating temperature. If any changes need to be made, the centrifuge must be given time to smooth out. Some lighter organic matter may take more heat to help keep optimal splits. More heat may also be required with lighter types of organic matter because they have a tendency to be burnt with chemicals. More heat will help to break the bond of the organic matter with the chemically burnt organic matter.

Injection and Chemicals

Some lighter types of organic matter often contain finer solids which in turn produce tighter emulsions. In such a case, injection and chemicals may be required. In most cases the best additive to use is water. If the centrifuge is not making clean splits between the solids and organic matter, make-up water can be injected into the centrifuge to help wash the organic matter off the solids. This is also helpful when the centrifuge 14 will not smooth out or maintain steady organic matter/water splits due to the lack of water in the mixture. Make-up water may also be necessary when pumping near the bottom of the feed tank 42 if there is very little water left in the tank. Some types of organic matter may have chemical additives and may have been over-treated or burned. In such cases a chemical such as a solids dispersant may be utilized. The right chemical and injection rate need to be determined for proper use.

Discharged Fluids

Most discharged water should be clear when viewed through a sample jar in some cases though the water may carry a brownish tint. This can come from the color of some chemicals carrying through with the water. The centrifuge should be adjusted to make the water as clean as possible and free of solids. Organic matter discharge should be as clean as possible and should be checked by "grind out" to determine whether it meets specifications. Specifications may vary depending on GPM through centrifuge and percentage of water and solids in the mixture. While the invention has been described with reference to preferred embodiment thereof, as will be apparent to those skilled in the art, certain changes and modification can be made without departing from the scope of the invention as defined by the following claims.

Example 2

Operation of the Fuzzy Controller For Waste Oil Separation

The input membership functions with the example input values, product oil BS&W = 0.75% and the percent oil in the product water = 0.95 %, are presented in FIG. 7. The BS&W membership functions are Low (L), OK, High (H), and Very High (VH). These membership functions are shown in the legend to the right in FIG. 7. The abscissa of FIG. 7 shows the range of BS&W values that belong to each membership function. The ordinate of the figure shows the value, or strength, of the membership in each function. In this example the BS&W reading of 0.75% has a membership of 0.3 in High (H) and 0.7 in Very High (VH). The percent oil in water product has only two membership functions, OK and High (H). From the example the percent oil in the product water of 0.95% has a membership of 0.15 in OK and 0.85 in High (H).

FIG. 8 presents the output, or manipulated variables, Feed Rate Change and Feed Temperature Change, with their membership functions. Each variable has five membership functions, and they have the same labels. The labels are: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB). These membership functions are similar to the input membership functions. The legend is to the right of the membership functions, in FIG. 8. This figure also includes the sixteen rules listed above. They are presented in the boxes to the left in the figure.

FIG. 9 presents the results of our example problem. In our example, eight of the sixteen rules are fired. The rules that are fired are the ones that have input variables with a membership value greater than zero. These rules are, one through four and nine through twelve. Eight rules were fired, four for each output variable, their was combined using the min-max rule. In this example, the product oil BS&W has a membership of 0.70 in the membership function Very High, and also a membership of 0.30 in the set High. The OIL IN the product WATER has a membership of 0.85 in the set High and 0.15 in the set OK. These values are listed on the outside of the boxes on the left side of FIG. 9. Rules one and nine each have two membership values associated with them. They are 0.7 for the Very High BS&W and 0.85 for the High OIL IN WATER. The min-max rule dictates that both rules will be fired with the minimum value , 0.7. This value is shown in the upper left hand corner of both of the rule boxes in FIG. 9. Similarly, rules two and ten are associated with the membership values of 0.7 and 0.15. Both of these rules are fired with the minimum strength of 0.15, as shown in FIG. 10. Rules three and eleven are associated with membership values of 0.3 and 0.85. They are both fired with a minimum strength of 0.3. Rules four and twelve are associated with membership

values of 0.3 and 0.15. Each of these rules are fired with the minimum value of 0.15. With the maximum portion of the min-max rule we compute the rule out put. Rules one through three have an antecedent of Negative Big (NB).The strengths of these rules are 0.7, 0.15, and 0.30 respectively. These values are shown in black in the upper left hand box in figure 4, (for the feed rate change). The maximum value of the three (0.7) was used for the resolution value of the three rules. The membership function that describes the change in feed rate as Negative Big (NB), is truncated at the value of 0.7 as shown in the top portion of figure 4. Rule four is the only rule that suggests that the feed rate change should be Negative Small (NS). It fired with the minimum strength of 0.15. As shown in FIG. 9, the membership function that represents a change in feed rate of Negative Small (NS), is truncated at a value of 0.15. The resolution of the out put from rules one through four is shown as the truncated membership functions in FIG. 9. The out put value used is the centroid of this truncated figure. In this case, it is about minus 1.5 barrels per hour (BPH). The centroid value obtained from this calculation is converted to a voltage signal and sent to the feed pump to reduce the feed rate accordingly. A similar process is used to resolve the feed temperature change. This is shown in the lower portion of FIG. 9. Rules nine through eleven have an antecedent value of Positive Big (PB). The maximum value of 0.7 was used. The membership function describing a feed temperature change of Positive Big (PB) was truncated at a value of 0.7. The twelfth rule calling for a change of Positive Small (PS) is fired with a strength of 0.15. The membership function describing a change in the feed temperature of Positive Small (PS) was truncated at 0.15. The output value for the feed temperature change is obtained as the centroid of this truncated figure. The output value is approximately plus 7.5 degrees Fahrenheit. This value is converted to a voltage signal

and sent to the feed heater to increase the feed temperature appropriately.

Recall that even though we have implemented the combination rules in the software of the control system, we were unable to find proper sensors for the oil in the product water. Consequently, the actual control system, senses only the product oil BS&W content, and the rulebase has been modified to reflect this situation. BS&W is usually the most important variable, so the actual system normally works quite well.

FIG. 10 presents an actual output from our project's last run. It represents the variable under control, the product oil BS&W, as a function of time. From 3:06 to slightly after 3:36, the control band is between 0.2 and 0.3 % BS&W. The desired value for the BS&W was less than 0.3%. The lower limit is set because it is uneconomical to run much below specifications. In this case the band was wider than desired because, for this particular day, with the given process conditions, the BS&W signal was somewhat noisy. FIG. 10 shows that the control system brings the product oil into the desired range, albeit a little slowly. The system sluggishness, in this case, was due primarily to the fact that power line voltage was low at the work site, because of large power demands elsewhere. This problem kept the feed heater from heating up as quickly as requested by the control system. After control was achieved, the set point was changed to see how quickly the control system would respond to a set point change. FIG. 10 shows the measured value of the BS&W coming into the new range before the centrifuge was shut down.

It will be understood that the above description of the present invention is susceptible to various modifications, changes and adaptations and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

What is claimed is:

1. A three stage centrifuge for separating a multi-phase mixture having at least one solid phase component, and at least two gravitationally separable liquid phase components, which liquid phase components include at least one higher specific gravity liquid phase component and at least one lower specific gravity liquid phase component, said centrifuge comprising:

a generally cylindrical shaped rotatable bowl having a tapered beach section of a reduced cross section with said bowl rotatable to separate the mixture into components by centrifugal force;

at least one pair of baffle plates mounted inside said rotatable bowl, wherein said baffle plates are spatially separated in order to form a pool of said lower specific gravity liquid phase component therebetween;

a third baffle plate, inside said rotatable bowl, disposed between said pair of baffle plates for controlling the purity of said lower specific gravity liquid phase component that is removed from said rotatable bowl, wherein said third baffle has at least one opening to allow said lower specific gravity liquid phase component to flow through the third baffle;

drive means for rotating said rotatable bowl;

pumping means for moving said mixture through at least one mixture inlet and into said rotatable bowl;

inlet control means associated with said mixture inlet for controlling the flow of the mixture into said rotatable bowl to prevent the disruption of separated liquid phase pools;

conveyor means within said rotatable bowl for conveying said solid phase components through said rotatable bowl to a solids discharge port;

drive means for driving said conveyor means;

lower specific gravity liquid phase discharge means including at least one adjustable lower specific gravity liquid phase discharge tube mounted among said baffle plates to remove the lower specific gravity liquid phase components from said lower specific gravity liquid phase pool and out of said rotatable bowl;

higher specific gravity liquid phase discharge means mounted within said rotatable bowl to contact a pool of relatively higher specific gravity liquid phase components and draw the higher specific gravity liquid phase components out of said rotatable bowl;

sensing and control means for controlling the conveyor means responsive to a torque exerted by the solids in the emulsion; and

a fuzzy logic controller means in communication with said centrifuge and responsive to conditions within said centrifuge for providing programmable control over the operation of the centrifuge.

2. The centrifuge as claimed in claim 1, wherein said fuzzy logic controller means is in communication with at least one centrifuge part selected from the group consisting of the drive means for the rotating bowl, the pumping means, the inlet control means, the drive means for driving said conveyor means, sensing and control means for controlling the conveyor means.

3. The centrifuge as claimed in claim 1, wherein said conveyor means comprises:

a conveyer auger which comprises a cylinder,

said cylinder comprising at least one opening to allow said lower specific gravity phase components to flow through said cylinder into a center portion of said centrifuge.

4. The centrifuge as claimed in claim 1 and wherein:

said at least one mixture inlet comprises a nozzle that directs the flow of said mixture as it enters said rotatable bowl.

5. The centrifuge as claimed in claim 1 and wherein:

said at least one mixture inlet comprises a three-sided baffle that directs the flow of said mixture as it enters said rotatable bowl.

6. The centrifuge as claimed in claim 1 and wherein:

said centrifuge is mounted on a trailer bed to facilitate the transport of said centrifuge.

7. The centrifuge as claimed in claim 6 and wherein:

said trailer bed has a sump pump built into its interior to contain materials that leak from said centrifuge.

8. The centrifuge as claimed in claim 6 and wherein:

said trailer bed comprises leveling jacks for purposes of stabilization.

9. The centrifuge as claimed in claim 1 and wherein:

said centrifuge is mounted on a telescoping centrifuge stand.

10. The centrifuge as claimed in claim 1 and wherein:

said conveyer auger includes twin lead flights to handle an increased volume of finer solid phase components.

11. The centrifuge as claimed in claim 1 and wherein:

said centrifuge is connected to button-type drain storage tanks.

12. The centrifuge as claimed in claim 11 and wherein:

said storage tanks are hinged to facilitate sample collection.

13. The centrifuge as claimed in claim 1 and wherein:

said rotatable bowl is fitted with contoured Teflon sheeting.

14. The centrifuge as claimed in claim 1 and wherein:

said centrifuge, a feed pump and at least two discharge pumps connected to said centrifuge are controlled by at least one motor controller.

15. The centrifuge as claimed in claim 14 and wherein:

said motor controller, a plurality of breakers and a plurality of transformers are mounted in a main control panel; and,

said main control panel communicates electrically with an operator panel mounted in an operator enclosure.

16. The centrifuge as claimed in claim 1 and wherein:

said centrifuge is connected to a heater control, said heater control comprising a digital key-pad type thermostat.

17. A three stage centrifuge for separating organic matter, water and solids from a mixture comprising:

a generally cylindrical shaped rotatable bowl at least 24 inches in length and at least ten inches in diameter having a tapered beach section of a reduced cross section with said bowl;

drive means for rotating said rotatable bowl;

conveyor means within said rotatable bowl for conveying solids through said rotatable bowl to a solids discharge port on the side of said rotatable bowl;

means for pumping mixture to a mixture inlet and into said rotatable bowl with a minimum of turbulence and with substantially no breaking of solid particles;

drive means for driving said conveyor means;

said rotatable bowl has at least three baffle plates mounted therein for forming a pool of organic matter there among;

organic matter discharge means including at least one adjustable organic matter discharge tube mounted among said baffle plates to draw organic matter from the organic matter pool and out of said rotatable bowl;

water discharge means mounted within said rotatable bowl to contact the water pool and draw water out of said rotatable bowl;

baffle means associated with said mixture inlet for baffling flow of mixture into the centrifuge to prevent disrupting of said organic matter and water pools; and,

sensing and control means for controlling said conveyor means responsive to a torque exerted by the solids in said mixture; and

a fuzzy logic controller means is adapted to allow the automatic control of one or more parts of said centrifuge, said parts selected from the group consisting of said drive means for rotating bowl, said means for pumping mixture, and said drive means for driving conveyer means.

18. The centrifuge as claimed in claim 17 and wherein:

a seal is utilized in an air space formed between a water discharge section and an organic matter discharge section to prevent condensation from forming in said air space.

19. The centrifuge as claimed in claim 17 and wherein:

said seal is machined from Teflon or Viton.

20. The centrifuge as claimed in claim 17 and wherein:

said centrifuge has at least one organic matter discharge tube which may be placed at optimum depths by means of precision ground notches that enable said tubes to be locked into pre-set positions.

21. In a three stage centrifuge for separating a mixture of petroleum, water and solids, that has;

a cylindrical shaped rotatable bowl having a tapered beach section of reduced cross section;

drive means for rotating the rotatable bowl;

a solids discharge port;

conveyor means within the rotatable bowl for conveying solids to said solids discharge port adjacent to the tapered beach section;

a mixture inlet to allow a multi-phase mixture into said rotatable bowl;

means for pumping said mixture through said mixture inlet and into said rotatable bowl;

drive means for driving said conveyor means;

a pair of baffle plates mounted inside said rotatable bowl for forming a pool of petroleum therebetween;

petroleum discharge means including an adjustable petroleum discharge tube mounted between the baffle plates for removing purified petroleum from said pool of petroleum and out of said rotatable bowl;

water discharge means mounted within the rotatable bowl for removing water from the rotatable bowl;

baffle means associated with said mixture inlet for baffling the flow of the mixture into the centrifuge in order to prevent the re-mixing of the petroleum and the water; and

sensing and control means for controlling the conveyor means responsive to a torque exerted by the solids in the multi-phase mixture,

an improvement which comprises:

a third baffle plate for providing improved control over the purity of a separated liquid product from a multi-phase mixture, wherein said third baffle is located inside said rotatable bowl between said pair of baffle plates, and

said third baffle plate comprises at least one opening to allow the flow of said separated liquid product through the third baffle plate.

22. A method of processing a mixture to separate organic matter from water and solids comprising:

agitating said mixture to provide a homogeneous mixture;

heating said mixture to a selected temperature;

pumping said mixture with a minimum of turbulence and substantially without breaking of solid particles in said mixture at a selected feed rate to a generally cylindrical rotatable bowl having a beach section of reduced cross section;

rotating said mixture within said rotatable bowl in order to separate said mixture into separate organic matter and water pools and to throw solids in said mixture outward by centrifugal force within said rotatable bowl;

conveying said solids within said rotatable bowl through said water pool formed in said beach area of said rotatable bowl to a solids discharge port;

discharging organic matter from said rotatable bowl through an organic matter discharge means having an organic matter discharge tube within said rotatable bowl placed into said organic matter pool and located among said baffle plates within said rotatable bowl;

discharging water from said rotatable bowl through a water discharge means placed into said water pool;

sensing and controlling a rate of conveying of the solids to said solids discharge port in response to the amount of solids; and,

baffling incoming mixture into said rotatable bowl to prevent disruption of said organic mater and water pools

wherein one or more parameters selected from the group consisting of said selected temperature, said selected feed rate and said rate of conveying solids are adjusted by a fuzzy logic controller.

23. The method as claimed in claim 22, wherein said organic material comprises oil.

24. The method as claimed in claim 22, wherein said organic material comprises animal waste.

ABSTRACT OF THE DISCLOSURE

An improved three-phased centrifuge for separating multi-phase mixtures is disclosed. The improvements include, modifying the shape of the centrifuge, providing at least three baffle plates to control the rate at which a low specific gravity phase liquid is extracted from the centrifuge apparatus, and allowing liquid components of the mixture to flow into the center portion of the rotatable centrifuge bowl when mixture volumes build up in the apparatus. The improved centrifuge is also automated with a fuzzy logic controller system to reduce the amount of specialized training that an operator requires to run the centrifuge. The improved centrifuge has a number of uses in waste disposal and material reclamation processes, including animal waste disposal processes, chemical refinery waste disposal processes, oil reclamation processes, and mineral reclamation processes.

S:\Documents\Current\Miller, Neal\Patent002\USPAT002MIL.wpd

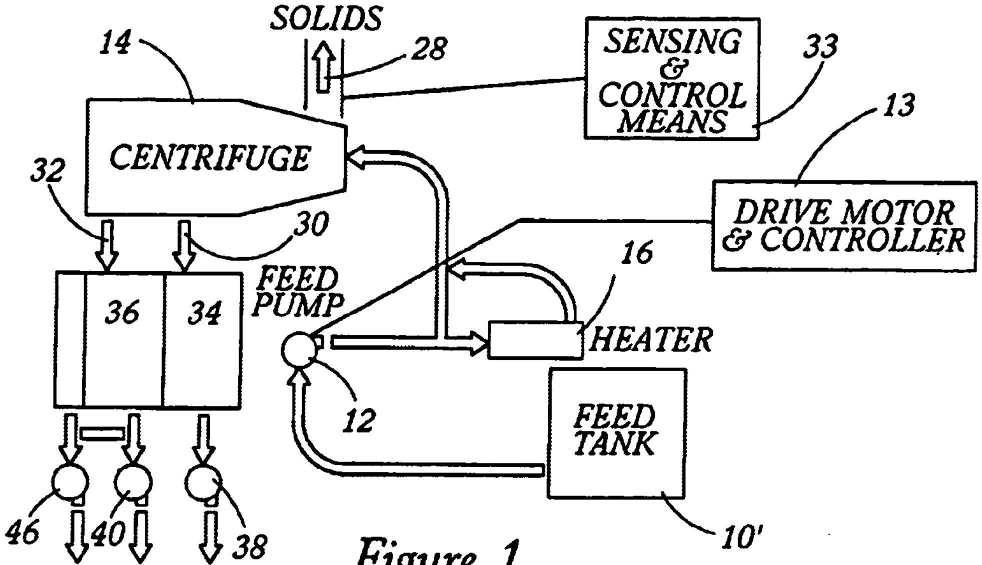


Figure 1

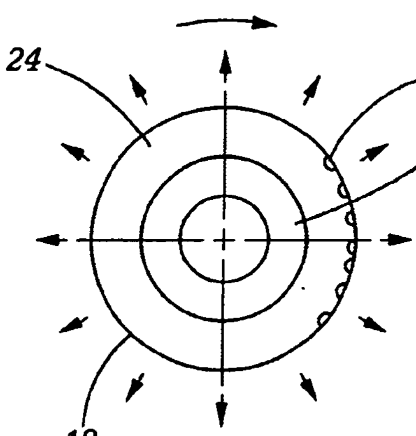


Figure 2

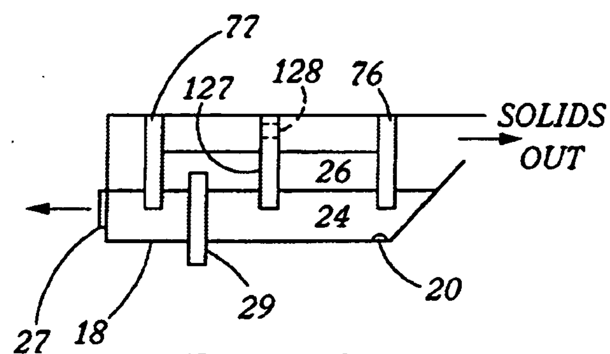


Figure 2A

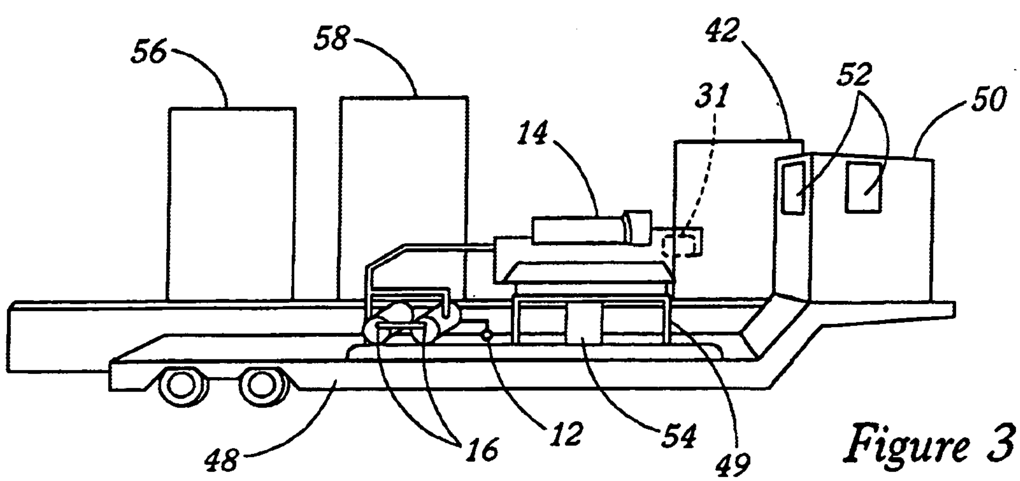


Figure 3

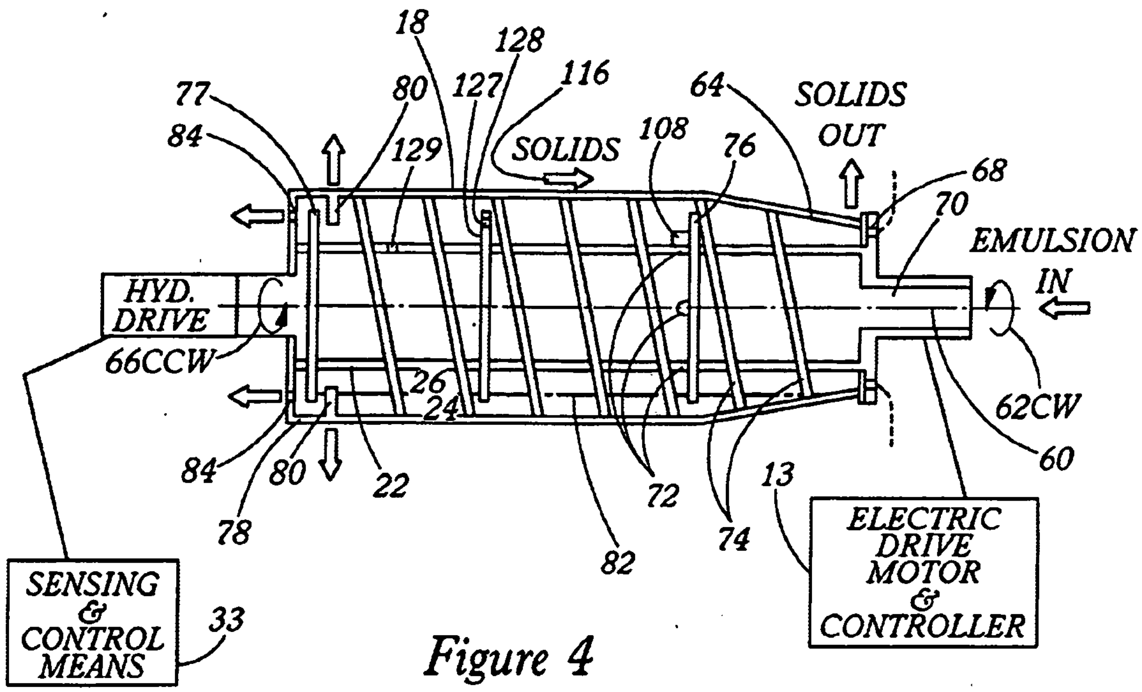


Figure 4

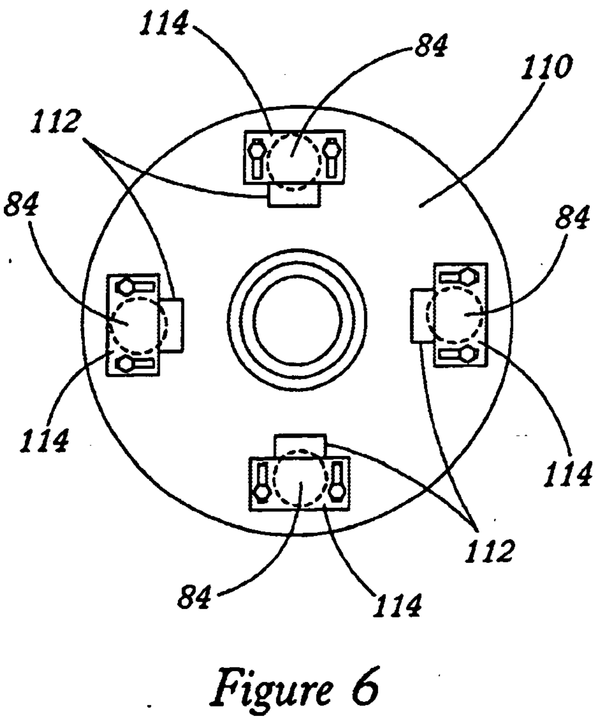
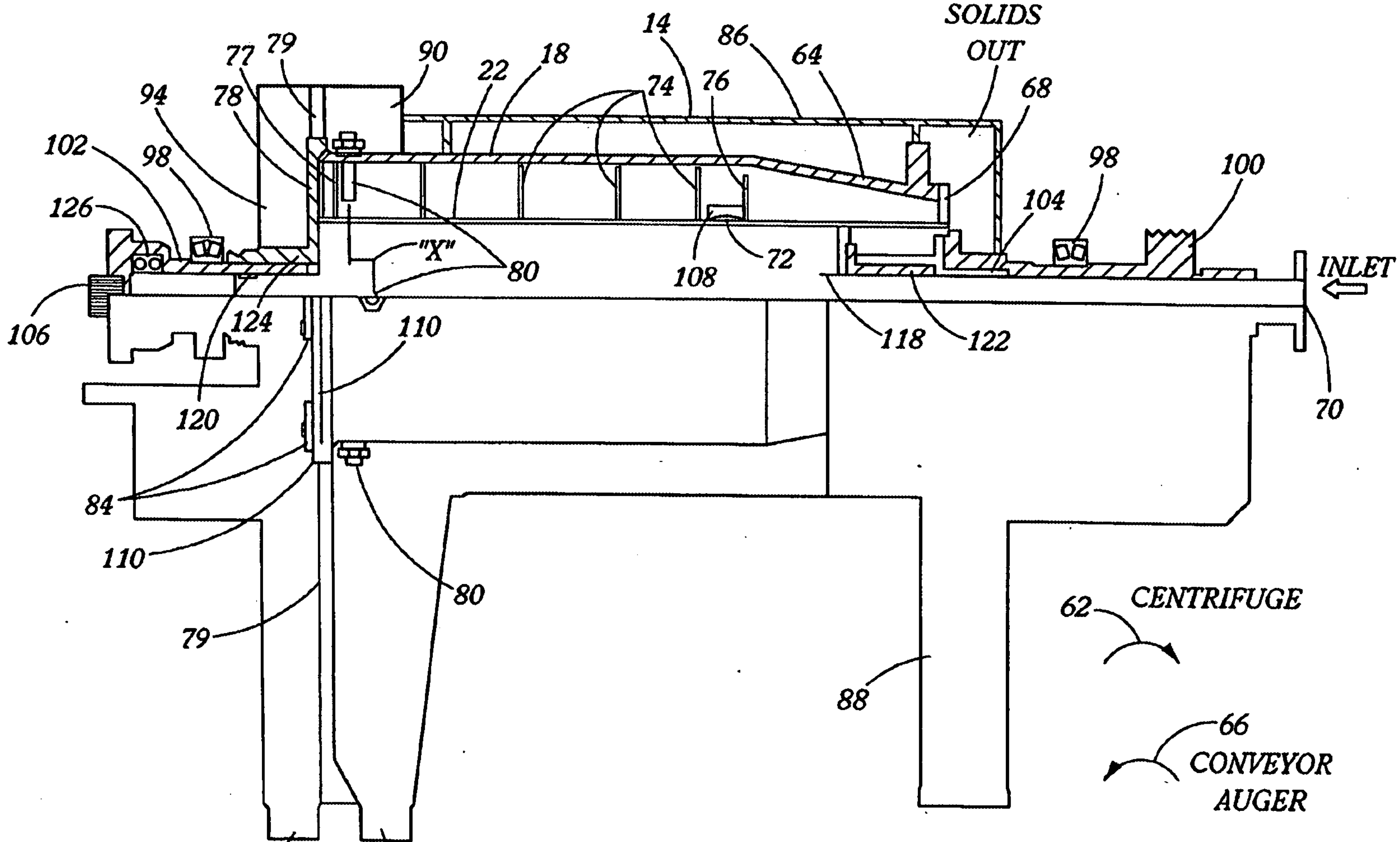


Figure 6



SOLIDS OUT
INLET
CENTRIFUGE
CONVEYOR AUGER
"X"
14
86
64
68
74
76
90
22
18
79
77
78
94
102
98
126
106
124
120
110
84
80
108
72
118
122
104
100
70
62
66
88
96
92

Figure 5

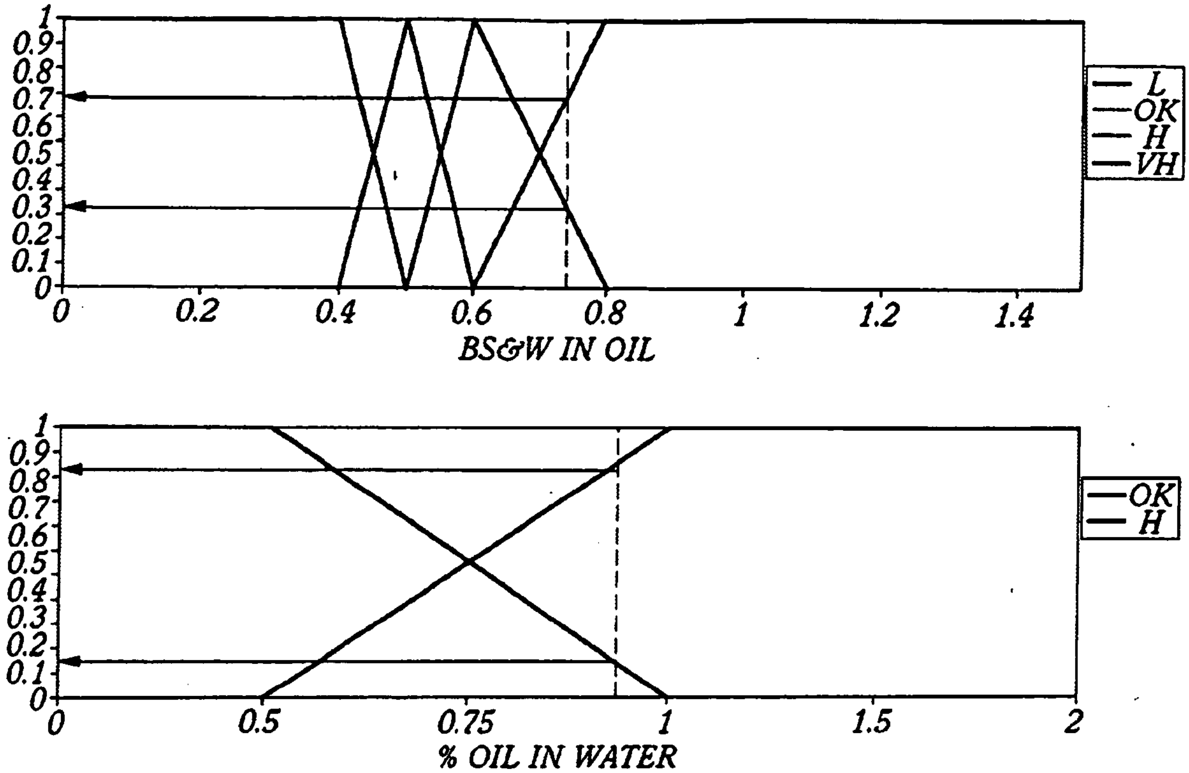


Figure 7

FEED RATE

BS&W	H	OK
VH	NB	NB
H	NB	NS
OK	NS	Z
L	Z	PS

OIL IN WATER

FEED RATE

BS&W	H	OK
VH	PB	PB
H	PB	PS
OK	PS	Z
L	Z	NS

OIL IN WATER

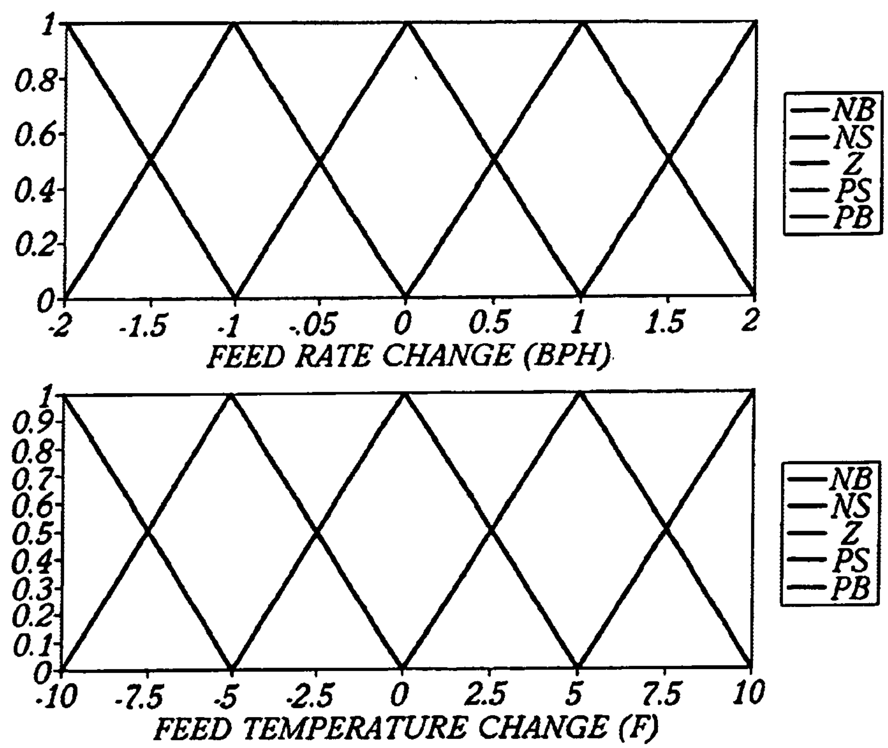


Figure 8

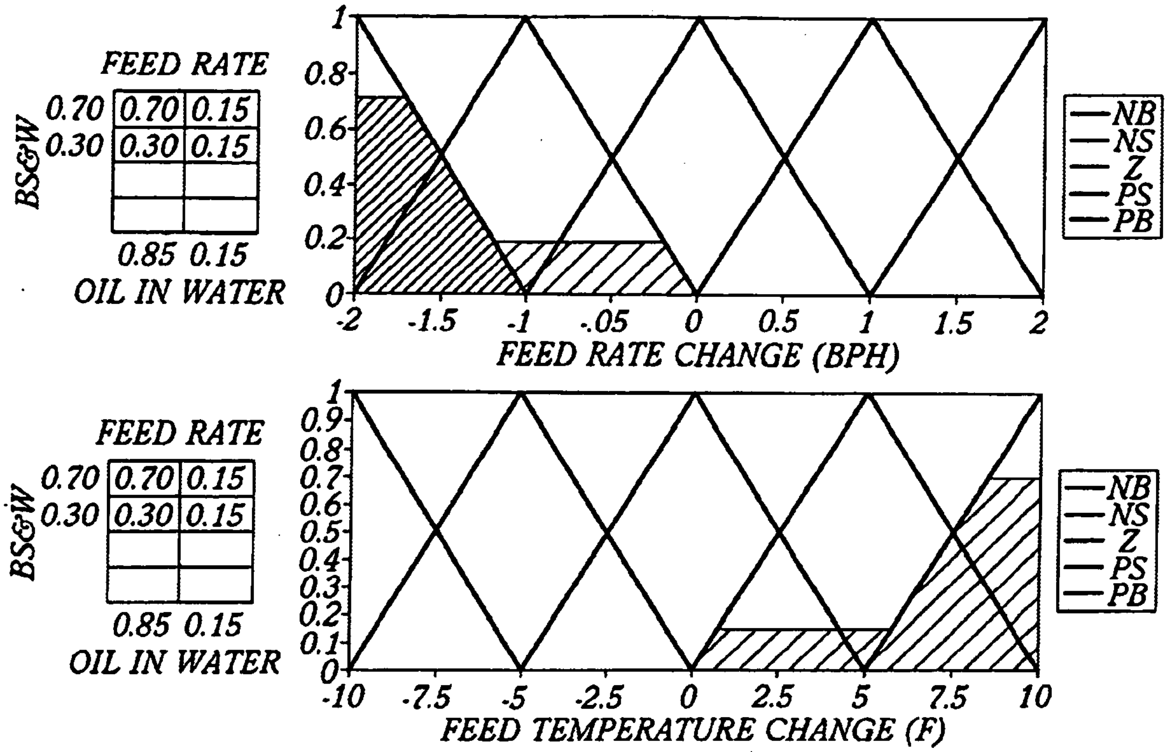


Figure 9

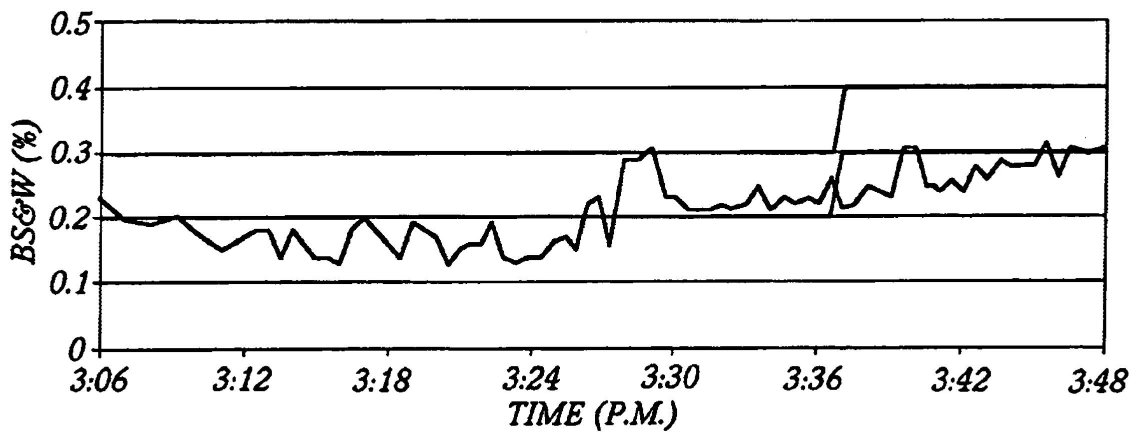


Figure 10

Centech Inc.
Centrifuge Technology
For Contaminated
Petroleum Products

Reserved for
Centech stuff
1999
– 2000
(Mostly)

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7/27/99 HCP

Electrical worker training

4 hrs -
2 hrs -

unplug the toaster

→ Take the training

talk to Mike

Basic electrical worker
Basic

Description

Centech Stuff

① Sensors – oil in water

② Sensors – solid oil *

(*) – Exper set up

a) – set up

b) – Chemical addition

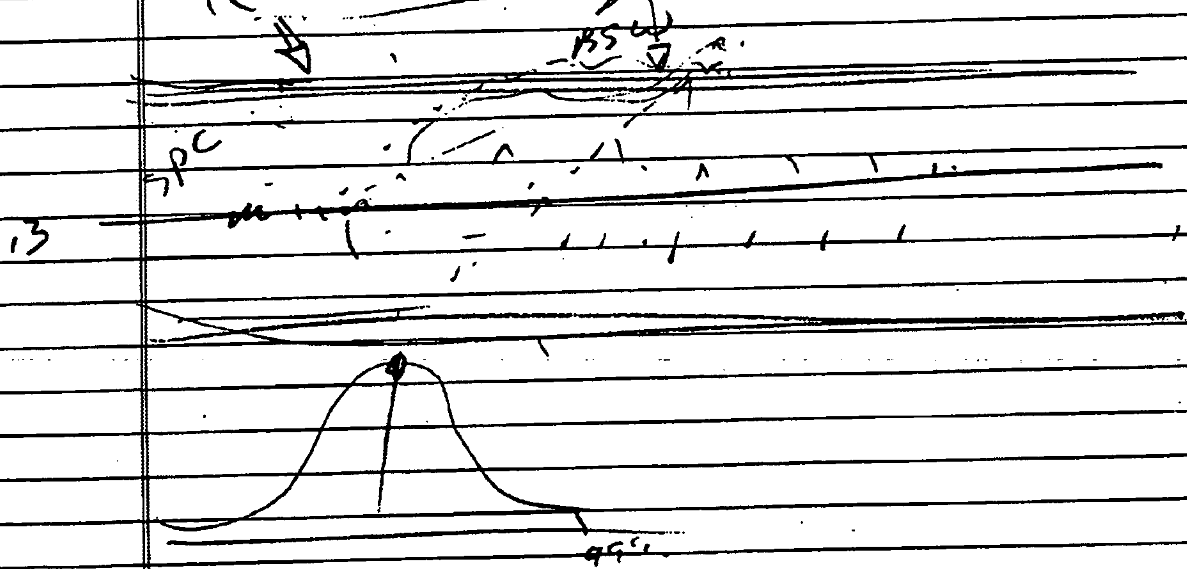
③ – Feed Forward Control

pump torquing up

feed change

plug of see flow meter

④ probabilistic



(5)- Bowl Speed Control

(6)- Adaptive sample time
- change according.

(7)- optimize RPM vs BS&W
for different case
Adaptability to every different Job.

(8)- hydraulics.
I think this is the Conveyor

Feed Forward control

Temp & BS&W in the feed.

↳ Temp & time @ certain volume

QMax } 16 input 6 in use

adaptor RS232 } ID

in Q

BS&W , Temp , heat rate , time @ temp

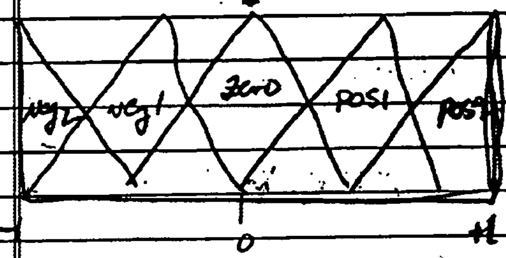
two flow meters

Δ

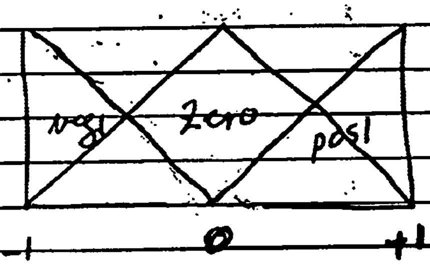
if BS&W (flow rate) → pump set point

& ~~[illegible]~~ speed

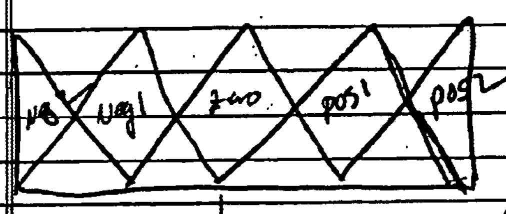
BS&W



Δ BS&W feed

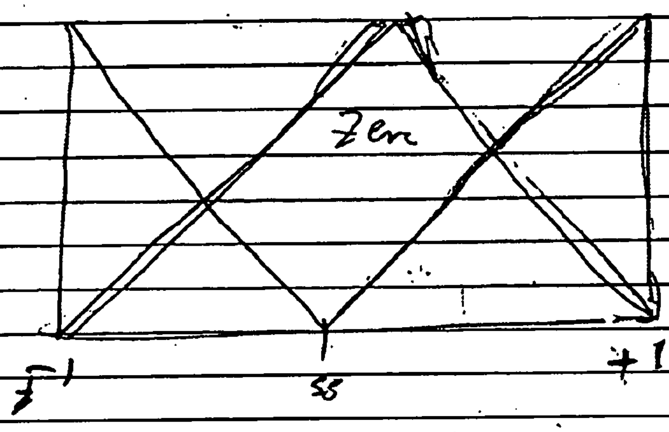


Δ flow rate



Both

Δ feed pump
Δ conveyor speed



oil rate → (TANK)
water rates →

Torque in feedback as well.

	ΔSSDW SS	Δ flowrate	⇒	Δ pump setpt/SS	Conveyor Δ torque
1	Neg 2	Neg 1			
2	Neg 2	Zero			
3	Neg 2	POS 1	⇒		
4	Neg 1	Neg 1			
5	Neg 1	Zero			
6	Neg 1	POS 1	⇒		
7	Zero	Neg 1			
8	Zero	Zero			
9	Zero	POS 1	⇒		
10	POS 1	Neg 1			
11	POS 1	Zero			
12	POS 1	POS 1	⇒		
13	POS 2	Neg 1			
14	POS 2	Zero			
15	POS 2	POS 1			

temp heat rate time @ temp heat rate
pump speed

Rules (1) if Q = QMAX PS = NEG

Rule (4) if Q = QMAX PS = NEG

Rule (7) if Q = QMAX PS = NEG

Rule (10) if Q = QMAX PS = POS

Rule (13) if Q = QMAX PS = NEG

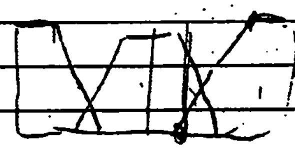
Rule (16) if Q = QMAX PS = NEG

Rule (19) if Q = QMAX PS = NEG

Rule (22) if Q = QMAX PS = NEG

Rule (25) if Q = QMAX PS = NEG

flow rate drops alot



BS&W =

	water	solid	heater	BS&W	FeedPump
(1)	NEG	NEG	NEG	NEG	zero V small
(2)	NEG	zero	NEG	NEG	zero
(3)	NEG	POS	POS V zero	~~[illegible]~~ zero	(large NEG)
(4)	zero	NEG	NEG	NEG	(small POS)
(5)	zero	zero	zero	zero	zero
(6)	zero	POS	POS	POS	(large NEG)
(7)	POS	NEG	POS	? ~~[illegible]~~ zero	(large POS)
(8)	POS	zero	POS	POS	(small POS)
(9)	POS	POS	(~~zero~~ V POS)	POS	(zero V small NEG)

Talking to the same

(20 x 20) (10.0 x 10.0) (10.0 x 10.0) Slag solids → feed pump drop

heater solid — feed temp — before heater — feed → conveyor speed — pump speed — heater temp — heater

	Change in Water	Change in Solid	Change in temp	CS	PS	Temp
(1)	NEG	NEG	NEG	zero	zero	POS → ↓
(2)	NEG	NEG	zero	zero	zero	zero
(3)	NEG	NEG	POS	zero	zero	NEG
(4)	NEG	zero	NEG	zero	zero	POS → ↓
(5)	NEG	zero	zero	zero	zero	zero
(6)	NEG	zero	POS	zero	zero	NEG
(7)	NEG	POS	NEG	POS	POS	zero
(8)	NEG	POS	ZERO	POS	POS	zero
(9)	NEG	POS	POS	POS	POS	NEG
(10)	zero	NEG	NEG	zero	zero	POS → ↑
(11)	zero	NEG	zero	zero	zero	zero
(12)	zero	NEG	POS	zero	POS	NEG
(13)	zero	zero	NEG	zero	zero	POS → ↓
(14)	zero	zero	zero	zero	zero	zero
(15)	zero	zero	POS	zero	zero	zero
(16)	zero	POS	NEG	POS	zero	POS → ↓
(17)	zero	POS	zero	POS	zero	zero
(18)	zero	POS	POS	POS	zero	zero
(19)	POS	NEG	NEG	zero	zero	POS → ↓
(20)	POS	NEG	zero	zero	zero	zero
(21)	POS	NEG	POS	zero	POS	zero
(22)	POS	zero	NEG	zero	zero	POS → ↓
(23)	POS	zero	zero	zero	zero	zero
(24)	POS	zero	POS	zero	NEG	NEG
(25)	POS	POS	NEG	zero	zero	POS → ↓
(26)	POS	POS	zero	zero	zero	zero
27	POS	POS	POS	zero	zero	zero

Safety Factor

Rethink

	rate Feed Pump	fee // BS&W	Power Heater vapour	Water	Solid	
1	large Neg	Neg	Neg	Neg	Neg	
2	large Neg	Neg	Zero	Neg	POS	[illegible]
3	large Neg	Neg	POS	Neg	POS	[illegible]
4	large Neg	Zero	Neg	Zero	Zero	[illegible]
5	large Neg	Zero	Zero	NEG	POS ?	
6	large Neg	Zero	POS	NEG	POS ?	
7	large Neg	POS	Neg	POS	(POS)	solid
8	large Neg	POS	Zero	NEG	POS	
9	large Neg	POS	POS	Zero	POS	[illegible]
10	Small Neg	Neg	Neg	Neg	Neg	
11	Small Neg	Neg	Zero	Neg	Neg	
12	Small Neg	Neg	POS	Neg	POS	
13	Small Neg	Zero	Neg	Zero	Zero	
14	Small Neg	Zero	Zero	Zero	Zero	
15	Small Neg	Zero	POS	Neg	POS	
16	Small Neg	POS	NEG	Zero	POS	
17	Small Neg	POS	Zero	POS	POS	
18	Small Neg	POS	POS	POS	POS	
19	Zero	Neg	Neg	Neg	Neg	
20	Zero	Neg	Zero	Zero	Neg	
21	Zero	Neg	POS	POS	Neg	
22	Zero	Zero	Neg	Zero	Zero	
23	Zero	Zero	Zero	Zero	Zero	
24	Zero	Zero	POS	POS	NEG	
25	Zero	POS	Neg	Zero	POS	
26	Zero	POS	Zero	POS	POS	
27	Zero	POS	POS	(POS)	POS	[illegible]
28	Small POS	Neg	Neg	NEG	Zero	solid suspend
29	Small POS	Neg	Zero	NEG	NEG	
30	Small POS	Neg	POS	Zero	NEG	
31	Small POS	Zero	Neg	Zero	Zero	Pump
32	Small POS	Zero	Zero	Zero	Zero	Pump
33	Small POS	Zero	POS	Zero	Zero	Pump
34	Small POS	POS	Neg	Zero	POS	steady solid
35	Small POS	POS	Zero	NEG	POS	"
36	Small POS	POS	POS	POS	Zero	

	feed Pump	BS&W	heater	water	solid
37	large POS	Neg	Neg	Neg	Neg
38	large POS	Neg	zero	Neg	Neg
39	large POS	Neg	POS	POS slg	Neg
40	large POS	zero	Neg	zero	zero
41	large POS	zero	zero	zero	zero
42	large POS	zero	POS	POS slg	Neg
43	large POS	POS	Neg	zero	POS
44	large POS	POS	zero	POS	POS
45	large POS	POS	POS	POS	Neg

heater Temp — look at [illegible]

Conveyor speed — look at Temp — possible 140-150

Pump Speed feed pump — 120°F 15-20 water — change [illegible]

temperature feed — 38°F — 60°-75°F (wet) 10°F Total

Water = 15% ⟹ 20% range & above — down to

Solid ⟹ 5% 80-95% — 50%

heater — [illegible] = 70% 25-30% [illegible] change

feed BS&W — 0–100% ⟹ ±10% No change

flow rate — 0 — 60 gpm Normal 6 gpm ± 2

Torque —

10 - gpm
6 - 9 gpm

20 gpm

10

high solid smaller 1/16" quality problem

Vis change slug of solid small change

Sample / large

Zero = ±30
Small = 30-45
[illegible] = 45 →

8/17/99

Team Leader's Meeting

U.C. has a different fiscal year
ends June 31.

Travel Budget.

Will over run by $50K.

* R T & U codes are not included.

* OSE auditors are back in town

- Office of security Evaluations.

- Engineering Council.

- Weapons Council ??

- wants EPE & DE involvement!!

Program Code & Money

- Salary - opens Next Monday

- 3 Weeks (turn around)

Bruce Matthews resigned.

Pulse Customer's about Next year's budget.

EXHIBIT D

LA-UR-99-5482

Approved for public release; distribution is unlimited.

Title: First Quarterly Report - Three-Phase Centrifuge Control System

Author(s): William J. Parkinson, ESA-EPE

Submitted to: National Petroleum Technology Office
Contact: John Ford, Tulsa, OK

Los Alamos
NATIONAL LABORATORY

First Quarterly Report – Three-Phase Centrifuge Control System

By

William J. Parkinson

Background — The Three-Phase Centrifuge

Neal Miller, president of Centech Inc, developed the three-phase centrifuge technology, discussed in this report. The three-phase centrifuge is an excellent device for cleaning up oil field and refinery wastes that are typically composed of hydrocarbons, water and solids. The technology is unique. It turns waste into salable oil, reusable water, and land fillable solids. No secondary waste is produced. The problem is that only the inventor can set up and run the equipment well enough to provide optimal cleanup. Even though Centech Inc. experiences some idle periods, demand for this device has far exceeded a one-man operation. There is quite often a need for several centrifuges to be operated at different locations at the same time. This has produced a demand for an intelligent control system, one that could replace a highly skilled operator, or at least supplement the skills of a less experienced operator.

Both the setup and control problems are ideally suited to fuzzy logic, since the centrifuge is a highly complicated machine that is set up and operated entirely by the skill and experience of the operator. In a previous project a rudimentary fuzzy control system was designed for and used on the centrifuge, demonstrating the feasibility of the fuzzy control approach.

For full control, the centrifuge requires a multi-input, multi-output (MIMO) control system, with some feed-forward capability. The feed-forward capability is required because, in the field, the centrifuge will often encounter feed conditions that vary widely as a function of time. The current control system is a multi-input, single-output (MISO) control system with no feed-forward capability.

The control problem is a classical fuzzy logic problem, since the centrifuge is a highly complicated machine operated entirely by the skill and experience of the operator. The centrifuge is a non-linear, time variant, multi-variable plant. It is a continuous-decanting-horizontal-bowl type with a helical conveyor. Spinning the feed mixture at high RPMs, creating a large centrifugal force separates the three phases. Under the centrifugal force the highest density material is forced to the wall of the centrifuge bowl. The feed mixture is continuously introduced at the centerline of the conveyor and enters the centrifuge bowl through ports on the conveyor. The solid is pushed from the centrifuge by the conveyor. The water and oil leave the centrifuge through ports at the opposite end of the centrifuge.

In addition to the centrifuge, the process requires pumps, a heater, and holding tanks. The heater is used to reduce the viscosity of the feed mixture and to improve the flow characteristics. A feed-holding tank is required because water or chemicals must occasionally be added to the feed mixture to achieve the desired separation. Three outputs, or controlled variables, are important. They are the amount of hydrocarbon in the solid product, the amount of hydrocarbon in the water product, and the BS&W (Basic

Sediment and Water) in the product oil. The upper limits on these variables are dependent on the customer's needs and the location. For example, in New Mexico oil is salable if the BS&W content is below 1%. In Wyoming the criteria is 0.3%. Similar variations are found in the solids and water, depending upon their final destination. These limits or specifications are met by controlling the feed rate and feed temperature. Bowl speeds and conveyor speeds (RPMs) are also important, but more difficult to control with this particular centrifuge. Lower limits for the controlled variables are defined by profit motives. The centrifuge operator is usually paid by throughput, so it is in his best interest to have the maximum feed rate possible. Higher feed rates reduce the quality of the product. In order to make the largest possible profit; the control system must operate the centrifuge as close to the upper limit of the specifications as possible.

The centrifuge is a large portable machine that is transported to various waste sites by truck and trailer. The waste material or centrifuge feed stream is different at each site. These wastes will always vary in composition and viscosity. But the largest variation is in the feed BS&W content, which can range from 90% to 10%. In addition, the centrifuge feed will often vary significantly with time at any single site.

The centrifuge setup procedure is probably more difficult and expert dependent than the complex centrifuge control system. Among other things, the initial parameters that must be set before the centrifuge is started up are:

- initial feed temperature,
- initial feed rate,
- initial bowl speed,
- initial conveyor speed,
- water weir height, and
- oil tube depth.

Other questions that need to be answered before the centrifuge is actually operated are:

- Do chemicals have to be added to the feed? If so, what chemicals and what concentrations?
- Does water have to be added to the feed in order to get an optimal separation?
- Does green oil have to be added to the feed?

The purpose of this project is to build an expert control system and an expert setup system so that the centrifuge can become more widely available, through leasing or some other means. In order to accomplish this, the centrifuge(s) will have to be set up and controlled by an oil field worker who is most likely not an expert in the field of three-phase centrifuge operation. The fuzzy expert setup consultant and fuzzy control system will make it possible to operate the centrifuge effectively.

Background --- The Fuzzy Control System

Until a few years ago, fuzzy control systems were rather rare. Today they are more common, because they have been determined to be useful.

A fuzzy control system is a control system based upon expert judgement and a semantic description of the process or control actions, as opposed to a purely mathematical model of the system. The control actions are rules that connect sets of input variables to sets of output variables. A fuzzy control system uses fuzzy sets of variables as opposed to the

"crisp" sets that are used with conventional expert systems. A simple example of a rule connecting two fuzzy sets is:

If the room is a little to hot, turn down the thermostat a little bit.

A corresponding crisp rule could be:

If the room is 72.5 degrees Fahrenheit turn down the thermostat one quarter of a turn.

The control action may be exactly the same in both cases; humans tend to think in terms of fuzzy sets, as in the first rule. If your expert is human and thinks in terms of fuzzy sets, it is very useful to design your control system in terms of fuzzy sets also. In the first rule, the sensed, or input (to the rule), variable is temperature and we are looking for it's membership in the fuzzy set (or membership function) " a little too hot". The fuzzy set or membership function "a little too hot" may range from 70 degrees to 80 degrees, with full membership in that set at 75 degrees. In this case, 72.5 degrees might have a membership in "a little too hot" of about 0.5. In fuzzy sets, memberships range from 0 to 1, where in "crisp" sets the membership is either 0 or 1. In our example there may be another fuzzy set for temperature named "just right". The range for this set may be 65 degrees to 75 degrees and the temperature of 72.5 degrees may have a membership of 0.5 in this set also. Now suppose that there is another rule that states:

If the temperature is just right do nothing with the thermostat.

The two thermostat action sets (output from the rules) are "do nothing" and "turn down a little bit". Let's assume that "do nothing" has a range from turn up ½ turn to turn down ½ turn, and "turn down a little bit" has a range from zero to down one full turn. In our fuzzy example, both rules will fire with an equal weight of 0.5 and the thermostat action will most likely be to turn down the thermostat about one quarter turn. (The exact value is determined by a technique known as defuzzification. There are several different defuzzification techniques available which all give similar but not identical results.)

It should be obvious from this example that as the temperature changes gradually, the control action will also be gradual. This is because the two rules weighted and then combined. This type of control action provides a nice smooth control surface. A crisp control system, that used sets, would provide a very rough control surface as the temperature and the control moved from one set to the next. That is because in the crisp system the membership is either total membership or no membership.

The centrifuge has many control variables that are easily defined in terms of fuzzy sets. The heater temperature is one of these variables and the fuzzy sets are similar, although not exactly the same, as our example. Feed pump speed is another such variable.

The dynamics of the centrifuge are extremely hard to model mathematically. Therefore we have chosen to model the control actions of the expert operator. Our expert operator describes his control actions in terms of fuzzy sets and rules. The success of our first, rudimentary, control system proved that this approach works very well for this project.

One of the most difficult aspects of developing a fuzzy-expert control system is interviewing the expert and obtaining all of the pertinent information. This information must be put in the form of rules and membership functions. It is usually a trial and error procedure because the expert and interviewer don't always interpret statements in the same way. The fuzzy-expert control system must be coded and then demonstrated for the expert and approved before it is put into service on real equipment. Much of the work for this quarter, listed in the following paragraphs, involved interviewing the expert and

turning his knowledge into rules and membership functions that are recognizable by the computer.

Milestones — Fourth Quarter FY99

The milestones to be completed in the fourth quarter of FY99 are as follows:

- Begin compiling the database necessary to develop the expert setup consultant.
- Optimize existing membership functions and implement control of throughput, temperature, centrifuge speed, oil quality and adaptive control of the sample rate.

Work Completed — Fourth Quarter FY99

We have taken two trips to Casper Wyoming this summer to talk to Neal Miller, president of Centech Inc. and knowledgeable expert operator, to gain more insight and information into the machine setup, control, and other problems.

Task One

The first milestone, "Begin compiling the database necessary to develop the expert setup consultant", has been completed successfully. We have obtained a great deal of expert information that will make it possible for non-experts to setup this centrifuge or a similar centrifuge, in order to perform the required separation, based on the properties of the waste or sludge that needs to be separated. We are currently working on turning this information into fuzzy rules and input and output membership functions that will make this information useable by others. The expert setup system will be quite comprehensive and it appears that based on our initial work here, that the setup system might very well contain more information and be more complex than the quite complex expert control system.

In addition to the setup system, Mr. Miller has requested a computerized startup checklist for items that need to be checked, but that don't necessarily require expertise, such as checking the power hook ups and power phases and checking the rotation on the pumps and conveyor. We will add this to our list of things to do because it certainly makes sense when we consider our overall goal of making this technology available to everyone who needs it. Customers who may lease one of these machines will probably need this kind of startup information and need it to be readily accessible.

The basic setup system is being designed to enable a non-expert to be able to select the proper initial settings for the following:

1. Water weir height.
2. Oil tube height.
3. Feed temperature.
4. Feed rate.
5. Conveyor speed.
6. Bowl speed.

The current control system alters the feed temperature and the feed rate to maintain or enable the centrifuge to produce the proper BS&W in the oil product. The proposed control system will add the input variables of conveyor speed and bowl speed to better

control the BS&W in the product oil as well as the hydrocarbon content of the product water and the hydrocarbon content of the solid product. (Much of the ability to tie in the hydrocarbon content of the water and the solids depends upon the availability of good online sensors to measure these quantities.)

The current, non-computerized, expert setup procedure relies very heavily upon the previous run settings. It also requires a grind out, or bench top centrifuge separation, and all possible knowledge of any previous treatment of the waste like the operating temperature for any refined hydrocarbon that might be present. Other important variables include the solids in the feed, the water in the feed, and the amount of hydrocarbon in the feed. Information about the amount and degree of emulsification and the presence of additional polymer chemicals in the mixture is also very important. The size of the solid particles can also affect the centrifuge setup parameters. Possibly the most important input information pertaining to machine setup is whether the waste mixture is paraffin or asphaltene base. The gravity of the oil phase is important. If the oil is heavier than water, green oil must be added to the system to make the average density of the hydrocarbon less than the water density. A minimum amount of water must be maintained in the feed mixture for proper separation of the phases. Finally, preliminary analysis will determine if chemicals must be added to make the separation, and if so, which chemicals and how much.

Task Two

The second milestone, "Optimize existing membership functions and implement control of throughput, temperature, centrifuge speed, oil quality and adaptive control of the sample rate", was addressed but not completed. The reason for not completing this milestone is because Centech Inc. has not had their centrifuge in operation since this project was initiated. This milestone cannot be completed unless the machine is in operation. The reason that Centech has not been in operation is because the Wyoming Department of Environmental Quality has been granting permits to Wyoming oil companies to allow them to place their oil waste on the roads. Apparently, this seems to have an economic advantage over centrifuging and separating the waste. Putting waste oil on the roads has not been permitted in Wyoming for several years. Hopefully this is a temporary situation and Centech will be in operation shortly.

The second milestone can be stated more clearly. The statement means that we will optimize our current membership functions for the rudimentary control system that is currently in place. The membership functions are the part of the fuzzy control system that defines the boundaries of the variables. For example, for the variable "feed rate", the fuzzy set or membership function "low" may range from zero to five barrels per hour. Since we were not allowed the luxury of optimizing our membership functions with the original control system, (They were built entirely with expert judgement.), the true range may be zero to four barrels per hour. The only way that we can optimize these membership functions is through trial and error while the machine is running. The membership functions for centrifuge speed have not yet been defined because this centrifuge is not currently a variable speed machine. That is, the bowl speed can not be changed while the machine is in operation. The centrifuge must be shut down and pulley on the drive motor must be swapped for one of a different size, manually. The variable

speed bowl is an innovation that is planned for the near future. This will make the control system much more versatile and flexible but also much more complicated. Adaptive control of the sample rates is something that has to be done in order to make sampling and control actions more precise. Sampling too often, causes over correction with feedback control systems. Not sampling often enough will provide inadequate control. Optimal sample times depend upon the system time constant. The system time constant is dependent upon the feed rate. The feed rate is one of the control parameters, so it is variable. An optimum sample rate will have to be adaptive to the changes in feed rate. This can be done best with operating information while the machine is running. We have set up the procedures to complete the second milestone but have not implemented them yet because the centrifuge has not been running.

Task Three

Instead of the second milestone for this quarter, we completed a good share of the second milestone for next year. That milestone is: "Investigate the use of feed-forward control techniques for feed disturbance rejection and for optimization of the delivery of separation-enhancing chemicals." We have obtained enough information from the expert in interviews to build a fuzzy expert-feed-forward control system. We are currently building this system on the computer and will have it working shortly. This system will use 27 fuzzy rules. It will adjust conveyor speed, feed pump speed, and feed temperature based upon the changes in water content of the feed, changes in the solid content of the feed, and changes in feed temperature. These corrections will be done in a feed-forward manner based on the expert's knowledge and ability to predict the centrifuge behavior in advance. The feed-forward control will make system changes in advance, preventing large upsets and reducing the burden on the feedback portion of the control system, which makes control changes only after they affect the product quality. There is a great need for the feed-forward control with the centrifuge, since the feed to the centrifuge tends to be non-homogeneous with time.

The feed-forward control can be implemented almost as soon as the centrifuge is put back into service, because a BS&W meter for the feed has already been purchased. One other complication with the feed-forward system is that we can only monitor changes in the BS&W in the feed, not the S (solid) and the W (water) separately. For this, we have developed a soft sensor, again based on the operator's expert judgement. The expert operator can tell what portion of a BS&W change in the feed is water and what portion is solid based on the temperature change in the feed and the change in flow through the feed pump at constant power. This soft sensor is another fuzzy expert system. It uses 45 rules that relate feed changes in the BS&W, feed changes in the temperature, and feed rate changes to changes in feed water content and feed solid content. This system should be easy to implement, although it is expected that it will require some fine tuning since the expert is not used to using a feed BS&W meter for his observations.

We have discussed, using feed-forward control to adjust chemical addition when it is required. For this operation we will some sensors that are different that the type we are using now. This part of the milestone is still in the planning stages.

Summary

The longer that we work on this project, the more impressed we are at the complexity of the problem and the depth of our expert's knowledge, his understanding of the separation process, and his understanding of the three-phase centrifuge.

We feel that we have made a good start on this project and have high expectations for continued success.

EXHIBIT E

LA-UR-00-0148

Approved for public release; distribution is unlimited.

Title: Second Quarterly Report - Three-Phase Centrifuge Control System

Author(s): William J. Parkinson, ESA-EPE
Ronald E. Smith, ESA-EPE
Neal Miller, Centech, Inc.

Submitted to: National Petroleum Technology Office
Contact: John Ford, Tulsa, OK

Los Alamos NATIONAL LABORATORY

Second Quarterly Report – Three-Phase Centrifuge Control System

By

William J. Parkinson and Ronald E. Smith
Los Alamos National Laboratory
Los Alamos, NM
And
Neal Miller
Centech Inc.
Casper, WY

Review

The three-phase centrifuge is an excellent device for cleaning up oil field and refinery waste. It also offers a potential solution for offshore clean up and oil recovery problems and it is being considered for in-line processing for both refinery and oil field operations. Unfortunately at the present time only Neal Miller, the inventor of the centrifuge system, can operate the system optimally. This limitation reduces the potential for this system to make an impact on US oil field and refinery environmental problems. The centrifuge, in addition to supplying clean up services, recovers pipeline grade oil from the wastes. Therefore it has the potential to make some impact on US supply problems.

Los Alamos National Laboratory has been asked to build an intelligent setup and control system for the centrifuge so that it will be easier for non-experts to operate the machine. This will make it possible to deploy the machine to many locations and more fully utilize its capabilities. We have been forced to address some of our milestones out of sequence, because this year the state of Wyoming has allowed operators to dispose of their waste oil on the roads. At first glance this seems like an alternative that is less expensive than the centrifuge, but this is not always the case. However this situation has kept Centech from operating the centrifuge in the normal manner and has limited the first Los Alamos efforts to computer work instead of fieldwork. We believe that Centech will be in full operation soon because on our last trip to Wyoming we spent some time with Mr. Miller and personnel from the Rocky Mountain Oil Field Testing Center (RMOTC) discussing the possibility of doing experimental work there. RMOTC is a DOE facility and the chances for a start up there early this year look very good.

In our last quarterly report we discussed three tasks. Two from the FY99 milestone list and one from the FY00 list. The FY99 milestone "Begin compiling the database necessary to develop the expert setup consultant." was worked on aggressively during the fourth quarter of FY99 and we continued work on this milestone last quarter (1st quarter FY00).

The FY99 milestone "Optimize existing membership functions, and implement control of through-put, temperature, centrifuge speed, oil quality, and adaptive control of the sample rate." was not completed because we have not been able to work on this part of the project due to inactivity of the centrifuge. We do need to be working with an operating centrifuge to complete this milestone. We have spent a great deal of time planning strategy to do this when we are able to work in the field. We made significant progress on the FY00 milestone "Investigate the use of feed-forward control techniques for feed

disturbance rejection and for optimization of the delivery of separation-enhancing chemicals." during both the FY99 fourth quarter and the FY00 first quarter.

Major Tasks Accomplished —first quarter-- FY00.

Task One

Task one for first quarter FY00 is the same as task one for the FY99 fourth quarter, "Begin compiling the database necessary to develop the expert setup consultant." In the first quarter of FY00 we went beyond the beginning stage. This quarter (1st quarter FY00) we have developed some rules and membership functions and implemented them on the computer. This is our first step in putting together a setup program for a reasonably complex problem. We will have to do several trial and error iterations with Neal Miller on this step because of the complexity of the setup problem. Here is an outline of our setup computer code:

1) Preliminaries
   a) Tie Power in.
   b) Open Electrical Panels.
   c) Check for proper Electrical Power Phases.
   d) Check the rotation
      i) The Conveyor.
      ii) The Electric Motors.
   e) Grease the Machine.
2) Start the initial setup with reference to the last job and adjust your settings from these points. (In the long run, with multiple centrifuges, this method probably won't be the best approach, but it is the best information that we have at this point. We have set the system up to log the data so that future jobs will have a larger reference base than just the last job.)--- There are two categories that must be considered here:
   a) Initial control settings
   b) Initial settings of non-control parameters, like oil tube and water weir heights.
3) Determine if the sludge is paraffin based or asphaltene based. This will determine how far you have to extrapolate from your last job.
4) Determine if possible, at what temperature the oil was originally worked or refined. This will help determine at which temperature to start your run.
5) Do a grind out or bench centrifuge test with the sludge.
   a) Determine
      i) BS&W
      ii) Oil in water
      iii) Oil in solids
   b) Determine the split between the water and solid phases.
   c) Look for an emulsion phase.
   d) Look for a polymer phase.
6) Make note of any chemicals that help with the split in the test tube.
7) The results from the grind out determinations are used to set control and non-control parameters to produce the required specifications for:
   a) Percent oil in water.

   b) Percent oil in solid.
   c) Percent BS&W in the oil.
8) The items that need to be adjusted for the setup that produce the required specifications are:
   a) Water weir height.
   b) Oil tube height.
   c) Feed Temperature.
   d) Conveyor speed.
   e) Bowl speed. (Currently the only way to adjust this speed is by changing the pulley size, so this adjustment is best done at startup. There are currently three speed adjustments.)
   f) Initial feed pump speed.

Currently, our rule base for setup includes only rules that determine current job settings (step 8, above) for current job requirements (percent BS&W etc. in product) based on the results of step 7 and the previous job settings that were used for the previous job requirements. These rules are still extremely rough and we have not yet included the variations due to extremely different oil working temperatures, the paraffin-asphaltene effect, or the differences caused by chemicals.

Task Two

The fuzzy feed forward control and soft sensor development is proceeding at a good pace. The developments from last quarter are:

1. Computerize or implement into the software the fuzzy rules and membership functions developed for the feed-forward control system at the end of FY99. Build the computer-centrifuge interface with the LabWindows® software. This system looks pretty good at this point and is ready to be tested when the soft sensor is perfected and the centrifuge is running and on the job.
2. Computerize or implement into the software the fuzzy rules and membership functions developed for the soft sensor system at the end of FY99. Build the computer-centrifuge interface with the LabWindows® software. This system still needs a lot of work. We are currently going through verification iterations with Neal Miller to insure that our system will produce realistic numbers.
3. We wrote a computer program, complete with a LabWindows® interface, for Neal Miller to use to test the soft sensor program described above. This was necessary because the soft sensor works in reverse from Mr. Miller's standpoint. That is, he is used to seeing the input variables as output variables. Without the test program, the verification process became quite confusing. Mr. Miller is currently using this program to develop test data for our system verification.

The current soft sensor utilizes 45 rules, utilizing three input variables, change in feed flow rate, change in feed BS&W, and change in feed heater power requirements to predict two variables required for the fuzzy feed-forward control system. The required variables are the change in the percent water in the feed, and the change in the percent

solid in the feed. In recent discussions with Mr. Miller it has become apparent that we may need to add a fourth input variable, the change in conveyor torque, to our soft sensor. This means we will need 135 rules to build a complete sensor. This also presents a small problem that we have yet to resolve. The problem is that conveyor torque is probably more properly a feedback variable. Since the feed-forward control system is being tied into the current and future feedback control system, the conveyor torque problem may not be a real problem. Figure 1, shows the control scheme for the fuzzy soft sensor and the fuzzy feed-forward control system. This figure doesn't include the feedback system, and it shows the conveyor torque reading as a question mark.

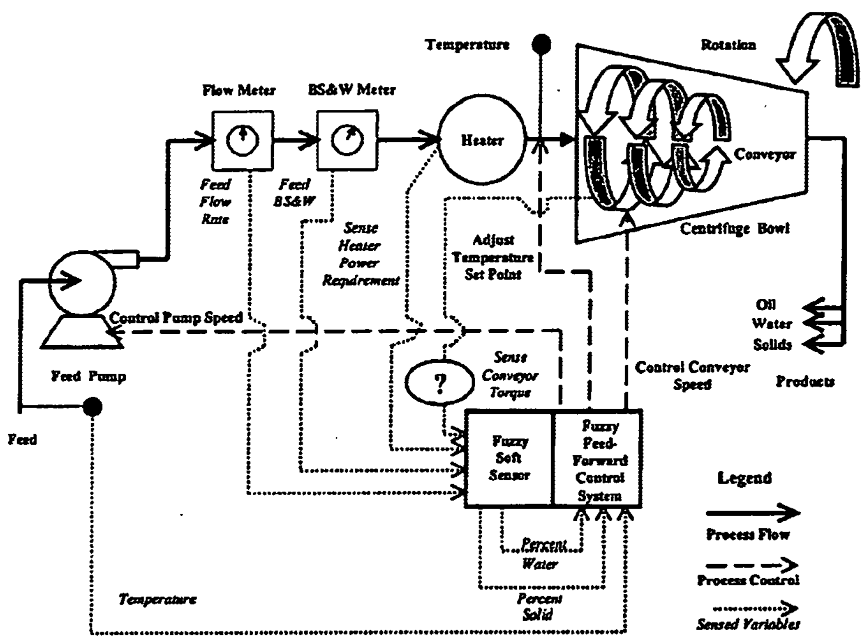


Figure 1. The schematic diagram for the fuzzy feed-forward control system and the fuzzy soft sensor.

EXHIBIT F

LA-UR-00-1662

Approved for public release; distribution is unlimited.

Title: Third Quarterly Report - Three-Phase Centrifuge Control System

Author(s): William J. Parkinson, ESA-EPE
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Neal Miller, Centech, Inc.

Submitted to: National Petroleum Technology Office
Contact: John Ford, Tulsa, OK

Los Alamos
NATIONAL LABORATORY

Third Quarterly Report – Three-Phase Centrifuge Control System

By

William J. Parkinson and Ronald E. Smith
Los Alamos National Laboratory
Los Alamos, NM
And
Neal Miller
Centech Inc.
Casper, WY

Review

Los Alamos National Laboratory has been asked to build an intelligent setup and control system for the three-phase centrifuge designed and is operated by Centech Inc. The Los Alamos work is an effort to make it possible for non-experts to operate the Centech machine. The three-phase centrifuge is a portable device that is used for cleaning up oil field and refinery wastes. It is also being considered for in-line processing for both refinery and oil field operations. Unfortunately, at the present time only Neal Miller, the inventor of the centrifuge system, can operate the system optimally. This limitation reduces the potential for this system to make an impact on US oil field and refinery environmental problems. The centrifuge, in addition to supplying clean up services, recovers pipeline grade oil from the wastes. Therefore it has the potential to make some impact on US oil supply problems. The Los Alamos control system will make it possible to deploy centrifuges to many locations at one time and therefore more fully utilize their capabilities.

Beginning this year, the state of Wyoming has allowed operators to dispose of their waste oil on the roads. Apparently some operators believe that this alternative is a less expensive waste disposal alternative than using the centrifuge. Even though this is not always true, the situation has kept Centech from operating the centrifuge in the normal manner and has limited the early Los Alamos efforts to computer work rather than fieldwork.

With the recent increase in the price of oil, operators are beginning to take another look at Centech, because of their ability recover saleable oil from the waste. Centech recently obtained an oil field job, with Wold Oil, in a field about 50 miles southwest of Casper, Wyoming. They were asked to clean up about 3,000 bbls. of waste oil and produce a product that was pipeline grade. The Los Alamos team was able to visit the site and carry out some of their assigned tasks that required the centrifuge to be in operation. The oil at this site is relatively clean. It is a paraffin base and contains about 10-15 % BS&W and a thin polymer phase. In April, Centech is scheduled to go to another site in Vernal, Utah and clean up a waste sludge that is asphaltene based and has a very high BS&W content. It will be very useful to compare set up and operating procedures required for the two different jobs.

Because of the earlier centrifuge inactivity we had been forced to address some of our milestones out of sequence. Now that Centech is in the field we are getting back into

sequence and by the end of next quarter, with a little luck, should actually be ahead of schedule.

Major Tasks Accomplished —second quarter-- FY00.

Background

This is actually the third quarter of the project.

In March, Centech obtained a contract for an oil field cleanup near Casper, Wyoming. The job was to recover pipeline grade oil from waste oil containing 10-15% BS&W in addition to some polymer. This job will take a little over three weeks if everything goes as planned. The Wyoming requirement for pipeline oil is less than 0.3% BS&W. Centech was easily able to produce "trace oil" or 0.1% BS&W or less, with their centrifuge. We were able to verify this both with bench centrifuge "grind outs" and our BS&W control sensor, residing on the centrifuge product tank.

In April, Centech is scheduled to go to Vernal, Utah to work on what appears to be tar sands mixed with an asphaltene type oil. This work will be a quite different than some of the projects that we have worked on with Centech in the past. It is extremely different than the current Centech project. The project will probably involve the addition of some chemicals to the feed stream. This addition is not needed for the current job. This work will provide a significant and welcome challenge. It will provide the experience that we need in order to apply our set up and control system to widely varying feed sources. It will be an excellent experience to go through the set up procedure and the chemical addition logic for Vernal scenario.

On the week of March 13-17, the Los Alamos team was on site with Centech near Casper, Wyoming. Our basic task was to get the old control system back on line after a long period of inactivity, and add some of our enhancements. A list of tasks attempted and completed during this trip is presented below.

- We rerouted our product BS&W sensor in order to get better and more timely readings. The old method was to place the sensor on the outlet from the product oil holding tank. Since this tank was normally pumped down only when it was full, the successive BS&W readings were often on the same product oil sample. This presented the control system with a random time delay. The new system added a pump around, where the oil from the product tank is continually pumped through the BS&W sensor. This technique provides a "real time" product BS&W reading for the control system. This is important since the product BS&W is the most important feedback variable.
- This system worked very well, with one exception. Periodically air is introduced into the sensor. We have not determined whether this is from pumping from a nearly empty product tank, or whether there is an air leak in our pump around system. We are trying to find the air leak and fix it and/or provide a numerical filter that will remove the noise signal frequency from the sensor reading.
- We ran some tests to determine the BS&W reading, or error, as a function of temperature. We have analyzed that data and will apply the correction algorithm that we developed on our next visit. Our system is currently set up so that we need to

calibrate the BS&W meter only once per job. The temperature dependent correlation will improve our precision and the confidence in our readings.

- We experienced some problems with our liquid-level control sensors that reside on the product oil and water tanks. The problem disappeared when we disconnected the tanks from our main control panel. This suggests some sort of short circuit that we were unable to isolate during our visit. Even though the liquid-level sensing of the product tanks is not part of our main control system, having automatic pump-off and level control will make the centrifuge easier to handle and more user friendly for future workers who are less experienced with the process.
- We also experienced some problems with our flow meter. The flow meter works on an ultrasonic principle, sending a sound wave into a fluid and receiving a signal back. In order to send the signal back, the fluid must contain particles. The flow meter does not work with pure clean water. The contaminated waste oil feed, found at this site, was relatively clean compared to some systems that we have worked with in the past. We actually tried adding product water to the feed to increase its BS&W content. After continued talks with the flow meter factory representatives, we concluded that there was a real problem with the meter and we returned it to the factory. The current feedback version of the control system will run without the flow meter in the system. The fuzzy controller does manipulate both the feed rate and the feed temperature, based upon the product BS&W, but it just adjusts them up or down from their current value. We don't necessarily need to know what that value is. So we were able to field demonstrate our control system, but only the old version. The new, improved, version will require knowledge of the flow rates. Our feed-forward controller, that is specifically designed to eliminate feed disturbance rejection, needs information about the amount of water, solids, and oil in the feed stream. This information will be supplied by our soft-sensor that requires knowledge of the feed rate.
- Centech has upgraded their control computer since the last time we ran the centrifuge control system. We have installed the control software and hardware on the new computer, but we are now encountering some difficulty. In the manual mode, the software does not allow some variables to be set. This was definitely not the case with the old computer. The exact same software run on the Los Alamos computers does allow these variables to be set. There is probably some machine-software incompatibility that we have to identify and remedy.

We had hoped that all of our equipment problems were behind us, but this is probably very unrealistic. We are, after all, working in the field with real equipment under real operating conditions. This is not a laboratory or controlled environment. When equipment has not been used for about a year, and has been transported over rough terrain, and operated in a severe out door environment, we have to expect some equipment problems. What we learn about equipment durability will probably help in the long run. Although the notes above make it sound like we had a difficult time during the last Centech visit, we actually accomplished quite a bit. We should have our equipment problems ironed out in short order.

Milestone Progress:

From FY99

1. Begin compiling database necessary to develop the expert setup consultant.
   - This work is ongoing. There is a lot of information to deal with, but work is progressing nicely. Some, but not all, of the information is in rule form. We expect to add significantly to this database when Centech begins work in Vernal, Utah, working with asphaltenes.

2. Optimize existing membership functions, and implement control of throughput, temperature, centrifuge speed, oil quality, and adaptive control of sample rate.
   - We attempted to optimize the existing membership functions, but our results were not good because of the defective flow meter. We will have to redo this task when the flow meter is repaired.
   - We have all of the other items under control and working, except the centrifuge speed. In the case of the centrifuge speed, Centech must purchase a variable drive unit, before we can work on controlling product quality with bowl speed. We are adding the control of the conveyor. This control variable is built into the fuzzy rule bases that we are using for feed-forward control.
   - The adaptive control algorithm is ready but cannot be implemented until the flow meter is fixed. The adaptive sample control is based on residence time of the material in the bowl. The residence time is controlled by the flow rate. The adaptive control algorithm requires knowledge of the flow rate.

From FY00

1. Determine and locate sensors suitable for the measurement of water quality, solids quality, centrifuge speed, solids loading within the centrifuge, and solids discharge rate.
   - We have identified some water quality measurement devices, but we must test them. We have had vendors in the past indicate that their device would work for our situation and they didn't. We had one experience like this with was a water quality device.
   - We are not having much luck with on-line real-time solids quality measuring devices to this point. I hope there is something available, at a reasonable price that actually exists.
   - The centrifuge speed sensor is just a tachometer. If and when we get a variable speed bowl, this will be easy to implement.
   - We believe that we have a device located that will measure the torque applied by the conveyor. This sensor will provide a measurement of the solids loading in the centrifuge. This "torque meter" is available through the manufacturer of the Centech machine. We intend to use it for determining "overload" and with our soft-sensor.
   - We intend to measure the solids discharge rate with a scale-type device. At this point, we are not certain how much value will be added by using this device.
2. Investigate the use of feed-forward control techniques for disturbance rejection and for optimization of delivery of separation enhancing chemicals.

- We have done a great deal of work on the feed-forward control system. We have included figure 1 from our last quarterly report, in this report as well, so that we can describe our progress a little better. We have acquired a BS&W sensor for the feed. It has a greater range than the BS&W meter used to measure our product oil. It is also less sensitive. This is adequate for our feed-forward work. The feed-forward rules are based on feed temperature change, percent water in the feed change, and percent solid in the feed change, as shown in figure 1. The problem is determining the percent change in the solids and the water from the feed BS&W measurement. This is the reason for using a soft-sensor. The soft sensor will be discussed in another section. This fuzzy computer code has been written, complete with membership functions, and is ready to be implemented. It does need the soft sensor in order to work.
- We have obtained information on the delivery of chemicals to the system when they are needed. This is usually determined, to some degree, after the initial measurement of the qualities of the feed stock. The actual amount is then fine-tuned based upon feed back results. We are hoping to capture some of this technique in the expert set up system and provide the fine-tuning in the control system. It is not clear yet how much of the fine-tuning can be provided by feed-forward techniques as opposed to feed back. We will probably get some "hands on" experience with chemicals at the Vernal operation.

3. Implement instrumentation necessary for measurement of water quality, solids quality, centrifuge speed, solids loading within the centrifuge, and solids discharge rate.
   - We are still re-implementing the old instrumentation and the feed BS&W sensor. One reason for not being further along with this task is the need to test sensors before purchase and we really need to test them under operating conditions.
4. Field demonstration of the improved control system.
   - We only have our small improvements working so far. So our "field demonstration" last week just proved that the old system will work with small improvements. We are pretty certain that we will have a good field demonstration of the updated system by the end of FY00, based upon our current progress.

FY01

1. Incorporate into the control system the optimized delivery of separation-enhancing chemicals based on feedback from the quality of the product oil.
   - We have done some planning for this step and feel that the Vernal, Utah test will be our best opportunity to try this concept.

Comments on the Soft-Sensor Work

We have developed a soft-sensor to determine the percent change in the feed water and feed solid based on flow measurements, feed BS&W measurements, and heater measurements. To this point, we have used 45 rules. These rules and their corresponding membership functions have been coded and are ready to implement. We have one problem. Even though the rules are well defined, the membership functions are not. The

idea behind the soft-sensor is this. If the feed BS&W changes, how much is due to a change in water and how much is due to a change in solids. Our expert, Neal Miller, President of Centech Inc., has provided the 45 rules. These rules are based on his experience with feed composition changes during his operations. He has a good understanding of what happens to the flow rates and heater requirements when feed composition changes occur. For example rule 1(in English) is:

If there is a large negative change in the feed flow rate, and a negative change in the feed BS&W, and negative change in the heater requirements the water percent change is negative and the solid change is negative.

This is a good rule, but we need to define the range of the membership functions:

- Large negative feed-flow rate.
- Negative feed BS&W.
- Negative heater requirements.
- Negative feed-water percent change.
- Negative feed-solid percent change.

We need to obtain numerical values from these membership functions so that they can be converted into the power requirements needed to change the conveyor speed, the pump speed, and the heater set point. On our previous visits to Casper, during the period that the centrifuge was not running, we spent hours working on these rules and ranges with Mr. Miller. We wrote some computer programs that he could use and respond to as if he were operating the centrifuge. We collected and analyzed a good deal of data from this work. This is helping us with the numerical description of the membership functions described above. One problem is that Mr. Miller is most comfortable with the two output membership functions. In other words, his experience is better suited to answer the question:

1- If the water change is negative 10% and the solid change is negative 10% then what is the change in feed flow, the feed BS&W, and the heater requirements.

Than the question:

2- If the feed flow is negative 10% and the feed BS&W is negative 10%, and the heater requirements are a negative 10% what will changes in feed water percent and feed solid percent be?

The rules, like rule 1 above, are in the form of question two. This is the form that we need for our soft sensor. Mr. Miller was very consistent in answers to question of type one. Nearly all of the computer questions answered mapped correctly back a proper rule antecedent. This helps in mapping out the membership functions but there is still a problem. Questions of type two have unique answers and questions of type one do not. For example there are seven different combinations of feed flow change, and feed BS&W change, and heater requirement changes that lead to negative changes in the feed water and feed solids. Again, all 45 rules stated in the form of rule two are unique. But we are not able to determine range and shapes of the membership functions for the 45 rules as well as we would like to, from answers to questions of type one.

We believe, based on our discussions with Mr. Miller, that adding the variable <u>torque placed upon the conveyor</u> to our rule base (high torque is an indication of solids loading), will help clarify our problem. The torque variable is represented by the question mark shown in figure 1. A problem with adding this variable is that our soft sensor will

probably require 240 rules instead of 45 rules. This represents a major task because it is hard to get 240 rules about one subject from any expert. Two approaches that we have started working on to help us build the larger system are:

1. A neural network based upon the data that we have collected from Mr. Miller. This approach shows promise but we will need a lot more data.
2. A new method for generating fuzzy rules from data. [1].

We will possibly end up using a combination of these two methods.
This has turned into a rather difficult problem but there are several ways to solve it, and we believe that we are close to solving it.

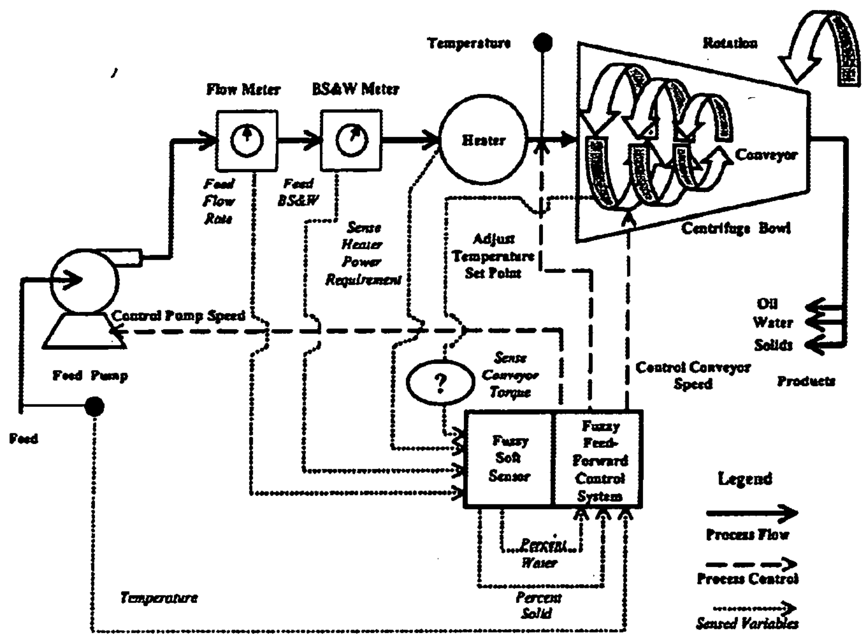

Figure 1. The schematic diagram for the fuzzy feed-forward control system and the fuzzy soft sensor.

Reference:

1. Wang, Li-Xin, and Jerry M. Mendel, "Generating Fuzzy Rules from Numerical Data, with Applications" USC-SIPI Report #169, Signal and Image Processing Institute,

University of Southern California, Department of Electrical Engineering-Systems,
Los Angeles, Ca.

EXHIBIT G

LA-UR-00-3234

Approved for public release; distribution is unlimited.

Title: Fourth Quarterly Report - Three-Phase Centrifuge Control System

Author(s): William J. Parkinson, ESA-EPE
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Neal Miller, Centech, Inc.

Submitted to: National Petroleum Technology Office
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Los Alamos
NATIONAL LABORATORY

Fourth Quarterly Report – Three-Phase Centrifuge Control System

By

William J. Parkinson and Ronald E. Smith
Los Alamos National Laboratory
Los Alamos, NM
And
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Centech Inc.
Casper, WY

Review

Los Alamos National Laboratory has been asked to build an intelligent setup and control system for a three-phase centrifuge that was designed and is operated by Centech Inc. of Casper Wyoming. The Los Alamos work is an effort to make it possible for non-experts to operate the Centech machine. The reason for the intelligent control system is that only Neal Miller, the inventor of the centrifuge, can operate it in an optimal manner. Without the control system this "one operator" limitation reduces the potential impact that this centrifuge technology will have on US oil field and refinery environmental problems. The three-phase centrifuge is a portable device that is used for cleaning up oil field and refinery wastes. It is also being considered for in-line processing for both refinery and oil field operations. The centrifuge, in addition to supplying clean up services, recovers pipeline grade oil from the wastes. Therefore it has the potential to help the US, somewhat, with oil supply problems.

Centech was unable to get jobs in the first two quarters of this project. (There were several reasons for this that were discussed in earlier reports.) Los Alamos was, therefore, unable to do the fieldwork necessary for some of the early milestones. Computer modeling was done instead and we proceeded with later milestones. With the recent increase in the price of oil, Centech is now getting a good deal of work and we are finding the opportunity to do the fieldwork that we intended to do earlier. Because of the earlier centrifuge inactivity we had been forced to address some of our milestones out of sequence.

Accomplishments —third quarter– FY00.

This is actually the fourth quarter of the project.

Since March, Centech has been working in the field off and on. This has allowed Los Alamos the chance to work in the field and accomplish some of the needed tasks to complete earlier milestones. In April, Centech was scheduled to go to Vernal, Utah to work on what appeared to be tar sands mixed with an asphaltene type oil. This work would have allowed us to extend our setup system significantly because the feed stock was quite different than feed stock from some of the other projects that we have worked on with Centech in the past. Unfortunately the Vernal work has been postponed indefinitely. Centech was able to work in the field in Wyoming longer than expected, however. We did schedule another trip to Casper (instead of Vernal) to perform some

more tests in the Casper oil field. Due to the **Los Alamos fire** we had to postpone that trip. Centech completed the fieldwork on this Casper project during the Los Alamos fire and we were not able to perform the experiments that we had planned. We did go back to Casper as soon as possible after the fire and were able to do some experimental work with the centrifuge. This was because Centech did not store the centrifuge in the usual manner between jobs. They made it available to us in the Centech shop yard. We could not actually run the centrifuge but we were able to pump some waste oil and water through the flow meter. We did not, however, obtain good readings from the flow meter with this mixture, possibly because we were unable to heat the oil-water mixture to a temperature that would allow the two phases to mix well. The flow meter experience has been a frustrating one. Since the flow meter reading is an important variable for both the feed-forward control system (via the soft sensor) and the feedback control system we have not been able to test our new control system under actual operating conditions. In an earlier trip to Casper, after several frustrating days, we determined that the flow meter was defective and sent it back to the factory for repairs. It has been repaired and we are still having problems with it. Currently Mr. Miller (Neal) is working in the field and has tested the flow meter on a real-well-mixed feed. The readings are intermittent. We have been in touch with a factory representative by phone and believe the problem is a short in the wiring of this newly repaired unit. We are going to Casper next week and will perform the required tests suggested by the factory representative. Hopefully, this will bring an end to our flow meter problems.

Once we have the flow meter working we can test our combined control system. We actually need to purchase or decide if we should purchase the sensor that measures the torque on the conveyor. We have had some difficulty in obtaining enough information about this device from the vendor. Because we are still not certain whether or not we will be using conveyor torque as an input variable, we have written two versions of the fuzzy soft sensor. One with the conveyor torque in it and one without. We will most likely use the version without the conveyor torque in it on our first attempt.

A good deal of work this quarter was devoted to tying together the combined feed-forward / feedback control system software with the proper coordination. A flow diagram for that system is shown in figure 1. Hopefully, we will be able to test this system next week.

This quarter we made some additional improvements to the expert set up program. These improvements came after some more discussions with Neal Miller (the expert) and after observing some procedures a little more closely. Even though we may not get the expected asphaltene information from Vernal, Utah, Neal is currently negotiating a contract with another company with an asphaltene problem. This kind of information will greatly enhance our expert set up system.

In our last quarterly report, we stated that Centech had upgraded their control computer since the last time we ran the centrifuge control system and they had encountered some difficulty. In the manual mode, the software would not allow some variables to be set. This turned out to be machine-software incompatibility that we were able to identify and remedy with a software patch from National Instruments Inc.

We hope now that all of our equipment problems were behind us. (After we finish with the flow meter problem.)

Status of Deliverables / Accomplishments:

FY99: (One Quarter Only)

Begin compiling database necessary to develop the expert setup consultant.

We have begun this database and put a great deal of data into the system. It is an ongoing task and will continue until the end of the project.

Optimize existing membership functions, and implement control of other variables.

We have completed the calculations for these items, but have not been able to test the results with the centrifuge yet. Some control items such as centrifuge bowl speed control are still undergoing Centech cost-benefit analysis.

FY00:

Determine and locate sensors suitable for the measurement of water quality, solids quality etc.

Several sensors have been located, but must be tested on the system. A real time solids quality sensor will be hard to find.

Investigate the use of feed-forward control techniques for disturbance rejection.

We have completed a great deal of work on the feed-forward control system. This system is ready to implement and test.

Investigate the use of feed-forward control techniques for optimization of delivery of separation enhancing chemicals.

This investigation is proceeding (Currently this information is included in the set up database. The set up database may be the best place for this function. Not the feed-forward control system.)

Implement required instrumentation.

We are still re-implementing the old instrumentation and the feed BS&W sensor. No totally new sensors have been added to the system yet.

Field demonstration of the improved control system.

We only have our small improvements working so far. Our "field demonstrations" so far have just proved that the old system will work with small improvements.

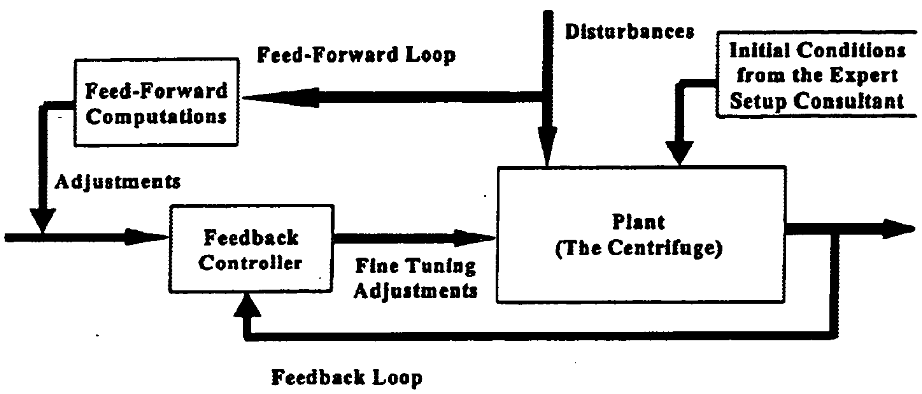

Figure 1. The schematic diagram for the fuzzy feed-forward/feed-back control system.

EXHIBIT H

LA-UR-00-4611

Approved for public release; distribution is unlimited.

Title: Fifth Quarterly Report - Three-Phase Centrifuge Control System

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Submitted to: National Petroleum Technology Office
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Los Alamos
NATIONAL LABORATORY

Fifth Quarterly Report – Three-Phase Centrifuge Control System

By

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Review

Los Alamos National Laboratory has been asked to build an intelligent setup and control system for a three-phase centrifuge that was designed and is operated by Centech Inc. of Casper Wyoming. The Los Alamos work is an effort to make it possible for non-experts to operate the Centech machine. The reason for the intelligent control system is that only Neal Miller, the inventor of the centrifuge, can operate it in an optimal manner. Without the control system this "one operator" limitation reduces the potential impact that this centrifuge technology will have on US oil field and refinery environmental problems. The three-phase centrifuge is a portable device that is used for cleaning up oil field and refinery wastes. It is also being considered for in-line processing for both refinery and oil field operations. The centrifuge, in addition to supplying clean up services, recovers pipeline grade oil from the wastes. Therefore it has the potential to help the US, somewhat, with oil supply problems.

Early in the project Centech Inc. was unable to obtain work so Los Alamos was unable to do the fieldwork necessary for some of the early milestones. Computer modeling was done instead and we proceeded with later milestones. Since the increase in the price of oil, Centech customers are lining up and waiting for their services. So we are finding the opportunity to do the fieldwork that we intended to do earlier. Since our last report we have spent three weeks in the field working with Centech personnel. Two weeks were spent at Cave Gulch near Casper Wyoming and one week in LaBarge Wyoming. Because of the earlier centrifuge inactivity we had been forced to address some of our milestones out of sequence.

Accomplishments —fourth quarter-- FY00.

This is actually the fifth quarter of the project.

We have finally found the problem with the flow meter. We have replaced the sensors. Even after one repair, the sensors that were returned to us with the repaired unit were intermittently faulty. We have since calibrated the meter twice, the calibration curve is stored in the computer and everything seems to be functioning well.

We reinstalled and re-calibrated the feed BS&W meter. This was a difficult job since the calibration technique required mixing oil and water in known quantities, pouring the mixture into the meter, and then taking voltage readings. Unfortunately, oil and water don't mix very well unless they are emulsified and stabilized. So our readings changed

quite rapidly. We added some emulsifier (dish washing soap) and things worked a little better, although in some cases it seemed to work too well. We have developed a calibration curve based upon the data that we obtained but we are not terribly confident of that curve, it is quite non-linear. We are asking Neal Miller to run grind outs or bench scale centrifuge tests to determine the exact BS&W for his feeds and then compare them with the BS&W meter reading, before we return to Wyoming. In this way we can verify our calibration and hopefully improve the calibration curve.

We have added a new pump and pump-around system to our product BS&W measurement system. The first incarnation of this system had the BS&W meter in the product line. Even though the BS&W in the product oil changes somewhat slowly, changes made in the product oil, due to changes in pump rate and feed temperature were only detected for each product pump down. Later we added a pump around system so that the current average BS&W in the product tank can be measured at every sample time. The pump that was used was one that was "available". It tended to overheat and leak air, so we got some spurious readings on occasion. The new system works very well.

We were finally able to find an instrument that would read torque and allow us to adjust the torque or speed of the centrifuge conveyor. Unfortunately this instrument was $10,000.00, and Centech decided that the benefit versus the cost was not great enough. Actually reading the torque and adjusting the conveyor speed by hand is not a high tech control problem. (It is not actually required to make it possible for a non-expert to run the system.) So Centech's decision seems justified. We have a problem, however, because the fuzzy soft-sensor required for our fuzzy feed-forward control system was using conveyor torque as one of the parameters to determine the change in the amount of solids in the feed. We had written another controller that did not use conveyor torque for this determination, but have less confidence in the predictions. In order to solve this problem, we have written (nearly complete) a computer program that describes the feed system physically. The model that we have built is not perfect but it is reasonably good. We have tested it on the centrifuge system by measuring pressure drops from point to point and we feel that the program is good enough for our purposes. We intend to use the computer program to test the rules and the membership functions used in our fuzzy soft-sensor. We need to be able to predict changes in feed composition (water-solid-oil) by looking at the change in the feed rate and feed heater requirements. The program requires, as input, changes to the feed composition. It predicts changes in the feed rate and heater requirements for the given feed composition changes. This is the reverse situation of what we are actually interested in. But we can use the program to verify the rules and membership functions that were already developed (minus conveyor torque information.). The program is basically a fluid dynamics model of the system based on Bernoulli's equation, continuity, and an energy balance. The program takes into account physical property changes based upon composition changes. Some examples are viscosity changes in the emulsion, density, and heat capacity changes. The program is nearly finished. We are still adding some physical property data to it. We should be testing it seriously in a couple of weeks and be able to verify and improve our soft sensor before actually running it on the centrifuge.

It is fortunate that we didn't have to write a computer model for the centrifuge itself, since we tried this once before and found that it is nearly impossible to model that

system. The feed loop is a different story. It is basically a fluid flow model with, difficult to model, mixture physical properties.

The new control system model without the conveyor torque in it is shown in figure 1. We apologize for showing this similar figure in several reports. We felt that we needed to keep current and show the updated version.

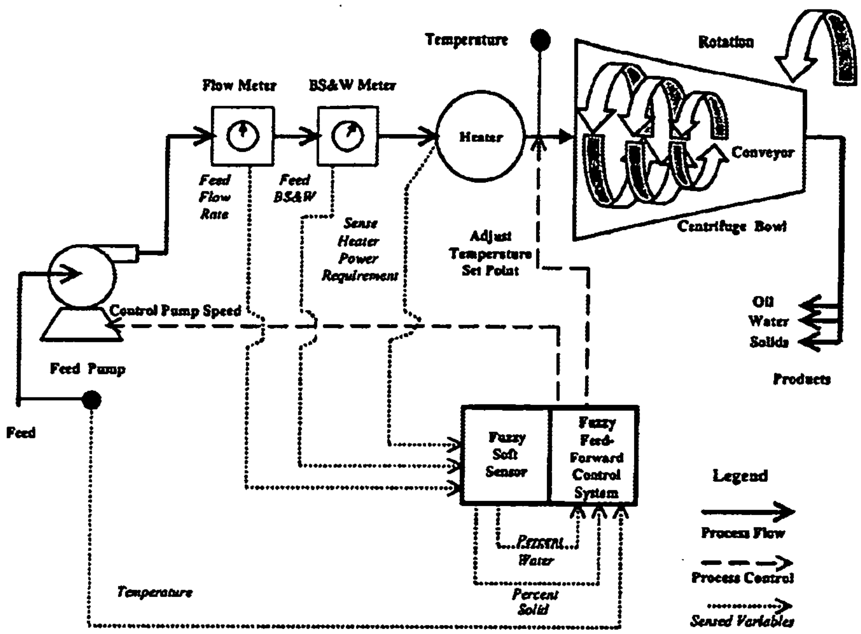

Figure 1. Updated diagram for the fuzzy feed-forward control system and fuzzy soft sensor (without Conveyor Torque sensor and Conveyor speed control).

Status of Deliverables / Accomplishments:

FY99: (One Quarter Only)

Begin compiling database necessary to develop the expert setup consultant.

We have begun this database and put a great deal of data into the system. It is an ongoing task and will continue until the end of the project. We have added a little bit more to this system this quarter.

Optimize existing membership functions, and implement control of other variables.

We have completed the calculations for these items, but have not been able to test the results with the centrifuge yet. But as of this quarter we still haven't gotten around to doing this.

FY00:

Determine and locate sensors suitable for the measurement of water quality, solids quality etc.

Several sensors have been located, but must be tested on the system. A real time solids quality sensor will be hard to find. One of the sensors that we had located, the conveyor torque sensor and controller was rejected because of the high cost. (And small benefit.)

Investigate the use of feed-forward control techniques for disturbance rejection.

We have completed a great deal of work on the feed-forward control system. This system is ready to implement and test. We have completed even more work on this system this last quarter.

Investigate the use of feed-forward control techniques for optimization of delivery of separation enhancing chemicals.

This investigation is proceeding (Currently this information is included in the set up database. The set up database may be the best place for this function. Not the feed-forward control system.) We haven't added to this database this quarter.

Implement required instrumentation.

We believe that we have finished re-implementing the old instrumentation and the feed BS&W sensor. No totally new sensors have been added to the system yet.

Field demonstration of the improved control system.

We only have our small improvements working so far. Our "field demonstrations" so far have just proved that the old system will work with small improvements. We seem to be still testing in the field rather than demonstrating.

EXHIBIT I

LA-UR-01-0013

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Title: Sixth Quarterly Report - Three-Phase Centrifuge Control System

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Los Alamos
NATIONAL LABORATORY

Sixth Quarterly Report – Three-Phase Centrifuge Control System

By

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Review

Los Alamos National Laboratory has been asked to build an intelligent setup and control system for a three-phase centrifuge that was designed and is operated by Centech Inc. of Casper Wyoming. The Los Alamos work is an effort to make it possible for non-experts to operate the Centech machine. The reason for the intelligent control system is that only Neal Miller, the inventor of the centrifuge, can operate it in an optimal manner. Without the control system this "one operator" limitation reduces the potential impact that this centrifuge technology will have on US oil field and refinery environmental problems. The three-phase centrifuge is a portable device that is used for cleaning up oil field and refinery wastes. It is also being considered for in-line processing for both refinery and oil field operations. The centrifuge, in addition to supplying clean up services, recovers pipeline grade oil from the wastes. Therefore it has the potential to help the US, somewhat, with oil supply problems.

Accomplishments —first quarter-- FY01.

This is actually the sixth quarter of the project.

This quarter we were only able to spend two weeks in the field with Centech Inc. One week was spent in Edgerton Wyoming just North of Casper and last week (December 11-15) in Evanston Wyoming. Each job had it's own unique problems.

Even though, we thought that we had all our equipment problems solved last quarter, we continued to be plagued with spurious measurements. This time we did find some serious damage to the feed BS&W meter that has been corrected and also a bad coaxial cable to the flow meter that has been corrected. Everything looks good now. One problem that we have with the sensors is that the entire feed-forward system is not running yet. Therefore Neal isn't observing the conditions constantly. This is because he is not really using the meters. The test runs that Los Alamos makes is where the problems show up, under constant heavy use. Another problem seems to be that these sensors were probably not designed to take the abuse that comes with moving the centrifuge from place to place and running under extreme temperature conditions. In spite of this things seem to be working ok now. We were set to test our systems when we went to Evanston last week, but Neal was having a hard time splitting the very heavy, " dead" (no light ends), paraffinic oil in very cold weather. The centrifuge was up and down and we didn't have any runs long enough, the entire week, to test our control system.

We have had some bad luck in testing our control system, but we have accomplished quite a bit in building it. It is very frustrating, not to be able to test and tune it. Here is a list of the good things that have happened this quarter:

- We have expanded the fuzzy soft sensor to include feed temperature. This means three times as many rules.
- We have expanded the neural-net soft sensor to include feed temperature as well. (We need to compare these two soft sensors in some actual runs to determine which one is best, or if a combination of the two works even better.)
- We have completed a physical based model of the feed system. (This model is designed to enhance or fill in any "holes" in Neal's knowledge. Neal has a very good experience based knowledge of a myriad of situations, but the soft sensor now has 135 rules which is a little bit too much knowledge to extract from one human. This is another reason for re-introducing the neural net program.)
- We have developed a "Fuzzy- statistical process control (SPC) technique" for combining the new feed-forward controller with the existing feedback control system.

Figure 1 shows the new modified Soft-Sensor-Control-System.

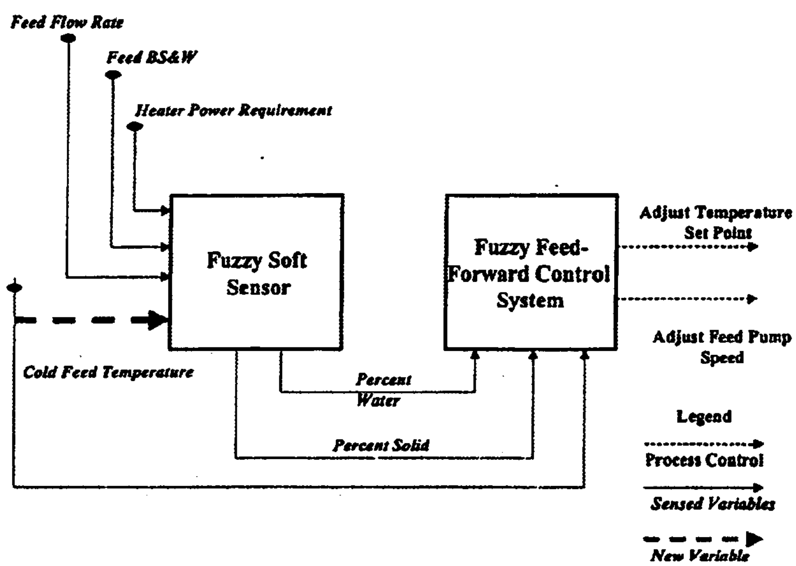

Figure 1. Updated diagram for the fuzzy feed-forward control system and fuzzy soft sensor (with new temperature measurement to the soft sensor.)

Figure 2 shows the block flow diagram for the combined feed-forward and feedback control systems. This system includes the "fuzzy-statistical process control (SPC) filter" and the conflict resolution program. The feed-forward controller is used to detect large changes in the feed that require process control adjustments before a major problem is encountered with the centrifuge. This is very important for many of Centech's operations, like stratified layers of material in the feed tanks or ponds. The fuzzy-SPC filter is required because the feed signals are quite "noisy" and we don't want to make changes in advance unless they are truly required. The feedback control system is continually working, making adjustments to the process after a product change has been detected. The conflict resolution portion of the controller makes sure that corrections to the process due to both feedback and feed-forward conditions are compatible with the goals of both controllers. This is usually dominated by the feed-forward portion because this is an event that is in the future, not in the past, and only significant changes are allowed because of the filter. However, some weight must be given to current action governed by the feedback controller.

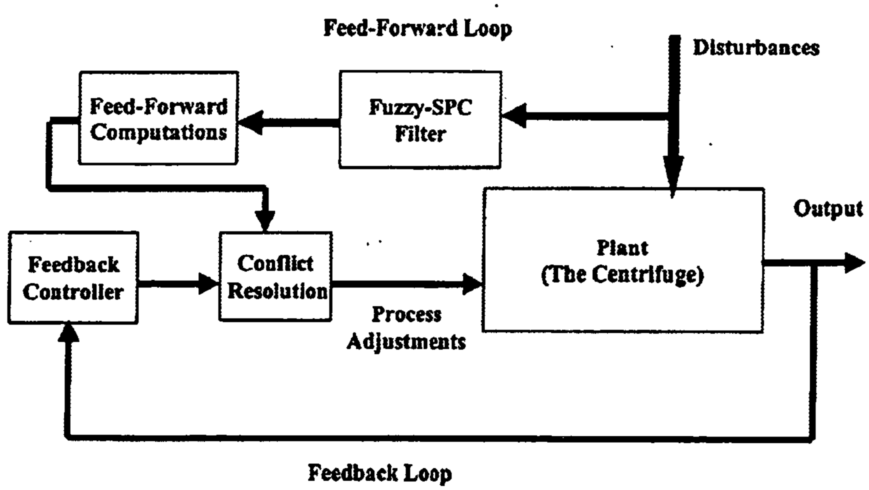

Figure 2. Block flow diagram for the combined feed-forward and feedback control systems.

The fuzzy-SPC filter is a rather unique trick to filter out the sensor noise, but it is quite appropriate for the centrifuge since the system time constant is in the order of minutes rather than seconds. The technique is compute intensive and probably would be too slow for something like an airplane control system. The idea is based on the principle of the

SPC X bar-R chart. It uses fuzzy logic because several variables are treated rather than one. Examples of X bar and R charts are given in figures 3 and 4 respectively.

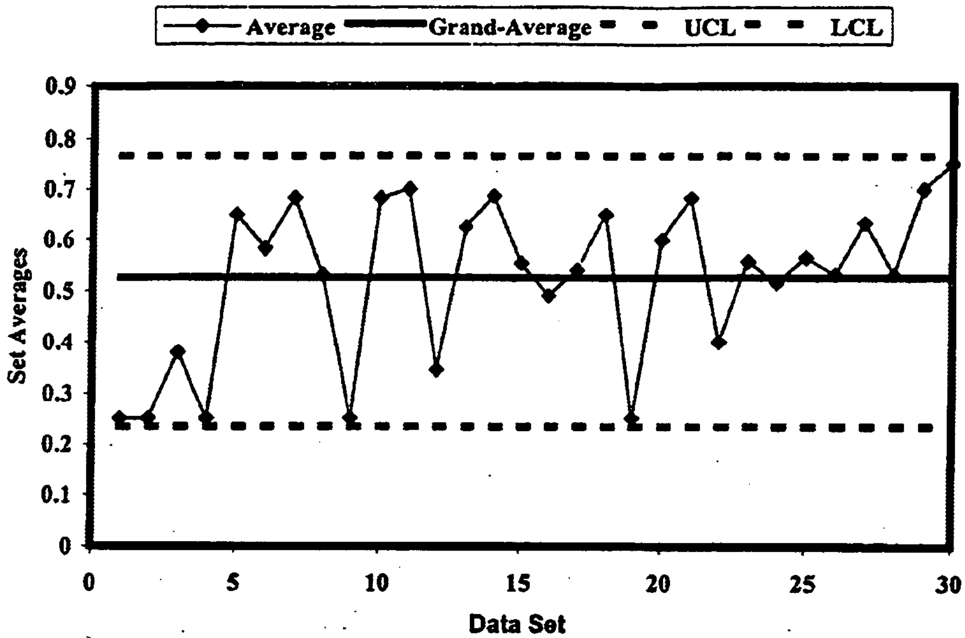

Figure 3. The X bar chart for the fuzzy SPC filter.

The X bar chart works like this:

- Data sets consisting of five points are taken 10 seconds apart of a quantity called "feed-change-magnitude" (Explained shortly).
- The average and range of each set are computed.
- After thirty sets (five minutes), the average-average or grand average and average range are computed.
- The upper and lower control limits are computed from statistical tables for both the X bar and R charts (figures 3 and 4.) These control limits are essentially three standard deviations above and below the mean lines.
- If X bar (average set) data stray beyond the control limits, the "feed-change-magnitude" is significant and the fuzzy soft sensor and feed-forward control is implemented.
- If the range data go beyond the control limits, it usually means that sensor difficulties are coming into play.

The X bar and R charts for this report were generated with the physical model of the feed system that we have just completed, a random number generator, and our fuzzy system for the fuzzy SPC filter. Figure 3 shows that the model feed has not changed significantly, but the last data point is heading for the upper control limit. Figure 4, the range chart needs some work because many of the data points are hanging at the upper

control limit. Since we are not using real sensors in the simulation, this doesn't mean too much. But we will look harder at this chart to make sure the calculations are correct.

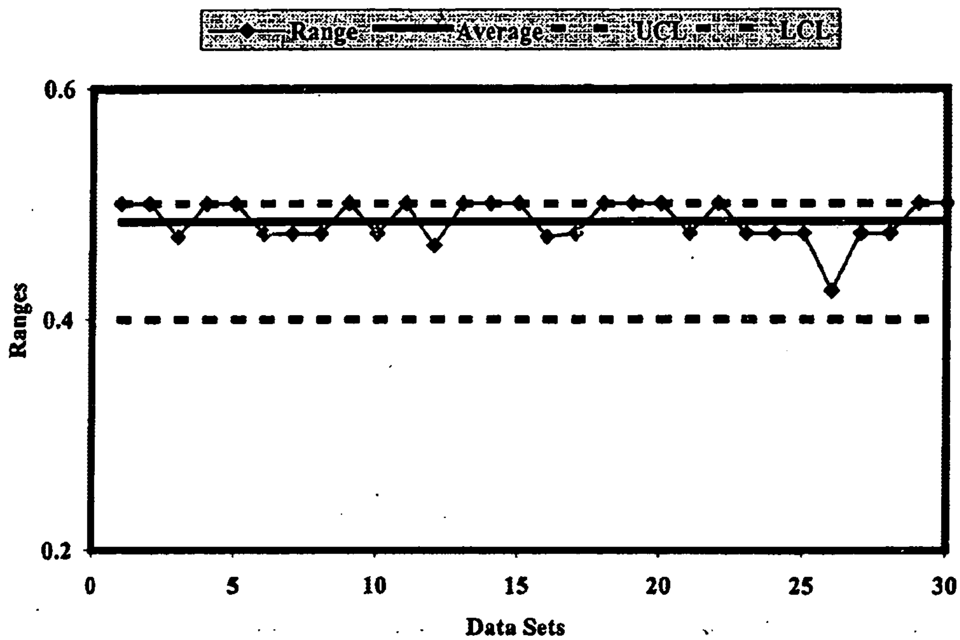

Figure 4. The R chart for the fuzzy SPC filter.

The "feed-change-magnitude" is computed with a fuzzy rule based system. If we look at figure 1, we see that four input variables are used in the soft sensor to compute two output variables, percent change in water and percent change in solid. All four of those variables, cold feed temperature, feed flow rate, feed BS&W, and feed heater requirements have measured random noise in them and they are not independent. This became quite apparent with the new physical model and the cold feed temperature and that is why that variable had to be added to the soft sensor rule base. So a change in say feed temperature might cause a change in flow rate that is not caused by a physical property change and therefore no change in the water or solid content. Our rule base takes this into account. There are sixteen rules, four input variables, eight input membership functions, one output variable and five output membership functions. The rules are of the form:

If Cold Feed Temperature Change is...and Feed Flow Rate Change is... and Feed BS&W Change is... and Feed Heater Requirement Change is... Then Feed-Change-Magnitude is...

All of the input membership functions are binary—**Positive** and **Negative Changes.** They are normalized between –1 and 1. The output has five membership functions **Large Positive, Small Positive, Zero, Small Negative, and Large Negative.** These membership functions are normalized between zero and 1 as can be seen in figure 3. The range 0 to 1 on the output is a prejudice of the authors for liking to use only positive numbers for output functions.

Other techniques are available for filtering the input and sensor noise. We feel this one is the best. It provides us with a technique for withholding a significant process change unless it is really needed. It provides us with a means to determine if the process feed is changing significantly, because we are making new control charts every five minutes. If the average sample mean or grand average continues to change over a period of time we need to know this and we can determine this from the charts. If the changes are slow enough they can be handled with the feedback system entirely. More abrupt changes will require the feed-forward system intervention. We can also determine changes in sensor noise and hopefully determine in advance if we are having sensor problems. (Which we have had plenty of in the past.) Note that once the initial control chart has be constructed (five minutes into the run), we can sample and control as much as we want. The continuing control chart upgrade goes on in the background.

On paper, with the simulation, this fuzzy SPC filter works great. It has been constructed with the physical model and data that have been collected while working on the centrifuge system. But this system like all of the rest needs to be tested and modified using real data when the centrifuge is running correctly and the sensors are functioning correctly. Hopefully this will happen in our next trip to Wyoming.

One problem that we may run into when we are working with the real system is some auto-correlation, since the system is essentially continuous. This means that some changes will have to be made possibly in time between samples or even sample size.